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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

AUGUST 1932

Symposium on Occurrence of Petroleum in Igneous and Metamorphic Rocks

EDITOR'S FOREWORD

During the compilation and editing of descriptions of the structure of oil fields for *Structure of Typical American Oil Fields*, volumes I and II, the writer observed that meager descriptions and incorrect conclusions regarding the occurrence of oil and gas in igneous and metamorphic rocks were perpetuated in the literature. In order to clarify the facts as learned from surface and subsurface geological studies, this symposium has been compiled as authorized by the Association in 1930.

Descriptions of important and unusual occurrences of bituminous matter are presented in individual papers. A search through the literature, together with solicitation from many geologists, has permitted the compilation of notes about many localities throughout the world where traces or seepages of bitumen, oil, or gas have been observed. These localities are described briefly in order to comprise a permanent reference, although few, if any, will lead to the discovery of petroleum in commercial quantities.

Many geologists have aided in compiling the data for the symposium. The name of each contributor is given wherever possible at the end of the note. Special acknowledgment is due to Margaret C. Cobb for searching the literature, Edward Bloesch for translating foreign literature, Winthrop P. Haynes for soliciting foreign contributions, Frederic H. Lahee for assistance in compilation and editing; Kenneth C. Heald, G. Clark Gester, H. J. Hawley, W. Dana Miller, W. B. Heroy, J. M. Muir, Arthur Wade, W. J. Millard, Clarence S. Ross, and many others for notes; and Frederick G. Clapp for preparing a classification of occurrences, a discussion of the literature, and descriptions of many occur-

rences which have been incorporated from a manuscript presented at the Association meeting in 1931.

SIDNEY POWERS

LIST OF COUNTRIES, STATES, AND PROVINCES MENTIONED IN TEXT

UNITED STATES AND ALASKA

ALASKA
ARKANSAS
CALIFORNIA
COLORADO
CONNECTICUT
ILLINOIS
MICHIGAN
NEW JERSEY
NEW MEXICO
NEW YORK
OREGON
TEXAS
VIRGINIA
WASHINGTON
WYOMING

NORTH AND CENTRAL AMERICA EXCEPTING UNITED STATES AND ALASKA

GREENLAND
NEWFOUNDLAND
CANADA
- QUEBEC
- ONTARIO
- BRITISH COLUMBIA

CUBA
MEXICO
NICARAGUA
SALVADOR

SOUTH AMERICA

ARGENTINA
BRAZIL
COLOMBIA
ECUADOR
PERU
VENEZUELA

EASTERN HEMISPHERE

ANGOLA
AUSTRALIA
BULGARIA
CZECHOSLOVAKIA
EAST INDIES
EGYPT
FRANCE
GERMANY
GREAT BRITAIN
- ENGLAND
- SCOTLAND
- IRELAND

GREECE
HUNGARY
ITALY
JAPAN
JUGOSLAVIA
MADAGASCAR
MANCHURIA
NEW CALEDONIA
NEW ZEALAND
NORWAY
PERSIA
PHILIPPINE ISLANDS
PORTUGAL
ROUMANIA
RUSSIA (U. S. S. R.)
SWEDEN
TURKEY
UNION OF SOUTH AFRICA

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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NATURE AND ORIGIN OF OCCURRENCES OF OIL, GAS, AND BITUMEN IN IGNEOUS AND METAMORPHIC ROCKS[1]

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ABSTRACT

Oil, gas, and residues of petroleum ranging from asphalt to graphite are found in igneous and metamorphic rocks. More than 15,000,000 barrels of oil have been produced from igneous and metamorphic rocks; one gas field produces from a basalt flow, and millions of tons of asphalt, representing the residue of more than 200,000,000 barrels of oil, are known in serpentine in one area—northern and northwestern Cuba. Seepages of oil connected with igneous intrusions led to the discovery of some of the largest oil fields in the world—in Mexico. Seepages and traces of oil, gas, and bitumen in igneous rocks point to the possibility of commercial production in many parts of the world where oil has not yet been found.

COMMERCIAL IMPORTANCE

(SIDNEY POWERS)

The commercial importance of oil and gas fields and of asphalt deposits associated with igneous and metamorphic rocks is not great. The only commercial gas field is Rattlesnake, Washington. The most important oil fields are in central Texas and are known as the serpentine fields, because oil is found in serpentine derived by hydration of tuffs, ferromagnesian lavas, and intrusive sills and laccoliths. Thrall, Lytton Springs (Lockhart), Yoast, Dale, and Chapman are the largest of the eight producing fields. Other oil fields are: Conejo Pass and Placerita Canyon, California; Furbero, Mexico; Bacuranao and Motembo, Cuba; Totumo, Venezuela; and Akita district, Japan (in small part). Taranaki, New Zealand, is listed, but production is from sedimentary rocks near an andesite intrusion.

[1]Manuscript received, May 1, 1932.

[2]Consulting geologist, Amerada Petroleum Corporation.

[3]Consulting geologist, 50 Church Street.

Production from these areas to the end of 1931 was as follows.

	Barrels
Serpentine fields, Texas*	13,344,600
Conejo Pass, California†	40,000
Placerita Canyon, California|	1,000
Furbero, Mexico‡	1,971,600
Bacuranao, Cuba||	112,900
Motembo, Cuba¶	5,000
Taranaki, New Zealand	70,000
Total	15,545,100

*Present daily production, about 2,850 barrels.
†Produced since 1892; little production in past few years.
|Produced for a short time only.
‡Present daily production, 180 barrels, of which well No. 27 makes 60 barrels. This well alone has produced about 775,000 barrels.
||Production for 1930 was 7,006 barrels; for 1931, 11,209 barrels (Harold B. Quarton, American consul, Habana).
¶This is naphtha; no steady production.

The Totumo field, Venezuela, is not producing commercially.

NATURE OF OCCURRENCES

(SIDNEY POWERS)

Oil and gas are derived from organic matter, largely of vegetable origin, deposited in fine-grained argillaceous and calcareous sediments. Inorganic theories for the origin of petroleum have been abandoned by all petroleum geologists.[1]

Generation of petroleum from organic matter takes place during the lithification of rocks by heat, pressure, and chemical changes. Oil occurs in rocks of very late Tertiary age in the Los Angeles basin, California; Gulf Coast, Texas and Louisiana; Isthmus of Tehuantepec, Mexico; Baku, Russia; and in other areas. Oil is known to have been formed in rocks of Ordovician age prior to Pennsylvanian time because of the presence of conglomerates of asphalt-impregnated Ordovician sandstone in Pennsylvanian conglomerates in the Arbuckle Mountains, Oklahoma.

Source rocks from which petroleum can be generated are necessary for petroleum accumulation. The quantity of oil or gas is directly proportional to the richness of the source rocks and to the reservoir extent. All the intrusive and extrusive igneous rocks containing bituminous matter either cut, or are in contact with, source rocks; hence, the rarity of occurrences of hydrocarbons associated with igneous rocks.

As agents in the generation, migration, and accumulation of petroleum, the rôle of igneous rocks intrusive into petroliferous sedimentary rocks may be active or passive; that of both igneous and metamorphic rocks not so intruded is entirely passive. Intrusive igneous rocks con-

[1] A very comprehensive discussion of the origin of petroleum appears in F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 770* (1924), pp. 731-55.

nected with petroleum deposits are usually, but not necessarily, of ferromagnesian type. This relationship may be fortuitous because most dikes, plugs, and sills cutting petroliferous rocks are ferromagnesian.

Petroleum may be generated by heat from intrusion. Conversely, no petroleum is genetically associated with intrusions which do not cut sedimentary rocks from which petroleum may be distilled. Petroleum associated with intrusions is notably scarce throughout the world, even where such intrusions cut petroliferous rocks. This fact has led to the belief by some geologists that while petroleum may be generated by the heat from an intrusion, the reverse is usually the case.

In general, granitic magmas are much higher in volatile constituents than ferromagnesian rocks, and their large size insures slow cooling and a gradual but long continued outward migration of these volatile constituents. Thus, any petroleum already present in contiguous rocks or generated by the heat of the granitic intrusive would tend to be swept away by the migrating volatiles. On the other hand, the ferromagnesian (basaltic) types of igneous rocks commonly form flows, sills, and dikes, where rapid crystallization of a highly fluid magma commonly tends to produce vesicular cavities. The limited escape of volatiles would exert a smaller tendency to sweep out the petroleum of the contiguous sedimentary rock; the more moderate heating of these rocks by the hotter but smaller intrusive, and the more porous character of such intrusives would all combine to favor distillation of petroleum into such rocks. This would be an effect parallel with the extensive metamorphism around granitic rocks, and the notable absence of such metamorphism around basaltic or diabasic rocks.

Osborne concluded from experiments that the heat of the intrusive distills water in the sedimentary rocks into steam, and hydrocarbons into gas or oil, and that the gas enters the igneous rock to fill the cavities and contraction joints. On cooling, vesicular gas bubbles would be in partial vacuum. Oil generated by heat in hydrocarbon-bearing sedimentary beds might thus migrate into voids in the intrusive rocks as cooling proceeds.[1] Heald, who has made an extensive study of such occurrences, agrees that the hydrocarbons are distilled in gaseous form and states that, "The gas forms and occupies vesicles and when the rock cools, condenses into liquid oil." This fact has led to the belief by some geologists that petroleum is not generated, but, on the contrary, is driven away by the heat from an intrusion.[2]

[1]Clarence B. Osborne, "A Theory to Account for Occurrences of Oil in the Vesicular Cavities of Igneous Intrusives," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 3 (May-June, 1923), pp. 288-90.

[2]K. C. Heald, personal communication, July 20, 1931.

Petroleum may migrate around and within intrusive rocks in joints and fissures, and also along the contact zone. Such migration is known to take place after cooling because bituminous matter is found within chalcedony or other crystal-lined walls. Migration may proceed both upward and downward along contacts. Also intrusive igneous rocks, just as faults, may act as barriers to stop migration and thereby trap oil which moves soon after or long after intrusion.

Petroleum may accumulate within unaltered intrusive rocks in pores (vugs, vesicles, amygdules) and in joints; within adjacent sedimentary rocks in shattered and brecciated zones and along the plane of contact. Seepages are most frequent from contact zones of large intrusions, such as volcanic plugs. The largest deposits are found in chemically altered intrusive rocks, porosity being induced by hydration to serpentine or by other chemical reactions.[1]

Most intrusive rocks which cut oil fields appear to have no connection with accumulation, as in the case of basaltic dikes cutting the Juan Casiano and Los Naranjos fields of Mexico, unless the intrusion produces anticlinal structure and the oil is trapped in sedimentary rocks (not in the igneous rocks) above or down the flanks from the intrusive, as in the oil and gas fields near the Sweetgrass Hills in Montana and Alberta.

The passive rôle of igneous and metamorphic rocks in petroleum accumulation is to furnish a reservoir. Few unaltered extrusive igneous rocks, such as ash, tuffs, and breccias, have primary porosity adequate for petroleum accumulation. In the Woodbine and other sands of northeastern Texas and southwestern Arkansas, in the Akita district of Japan, and in the Rattlesnake field, Washington, where oil and gas are associated with volcanic ash deposited with sand of sedimentary origin, the effect of the ash is to decrease porosity. However, oil is reported to be reservoired in ash or tuff in Mexico, Java, Sumatra, and Japan.

Many examples of the accumulation of petroleum at the eroded surface of igneous or metamorphic rocks have been reported. However, it is difficult to distinguish between arkose and unaltered basement rock in cores and cuttings from wells, and some reports of oil in basement rocks are probably based on mistaken identifications. Oil is reported from depths of several hundred feet within such rocks where it has migrated downward along joint planes, as on Copper Mountain, Wyoming, or along shear and joint planes of overthrusts, as along the Rocky Mountain Front Range in Colorado, Montana, and British Columbia. Oil is

[1] F. W. Clarke, *op. cit.*, p. 613. Clarence S. Ross states: "I feel sure that serpentines in general are the result of hydrothermal processes, but I do not feel so sure about serpentine tuffs. They may have been altered by the action of hot gases during explosive eruption, but such finely divided matter may have been altered in place by ground water." (Personal communication, May 25, 1932.)

reported in solid granite in oil fields along the buried Amarillo Mountains of Oklahoma and Texas, but such oil undoubtedly seeped downward in joint planes. These wells, from which oil is reported in unaltered granite, probably drilled through boulders of fresh granite or through tens of feet of fresh, jointed granite before they cut oil-bearing joint planes. Likewise, oil is produced from a penetration of 200 feet in solid schist which forms a buried hill underlying the San Onofre conglomerate of the Playa del Rey (Venice) oil field, California; from basal arkose and underlying basement-complex rocks in the Terra Bella oil field, California; from schist in the Placerita Canyon oil field, California; from trachyte at Totumo, Venezuela; from above and in a buried hill of granite under the Challacó oil field, Province of Neuquen, Argentina; from granite and overlying arkose in the Gemsah and Hurghada oil fields of Egypt. Oil is found in granite and basal arkose at Gebel Zeit, Egypt, and in several places in the Sinai Peninsula, Egypt, both as seepages and as showings in wells.

The existence of downward migration is more clearly proved by the foregoing examples. Oil may move downward several hundred feet or more. No similar proof is offered by oil fields in sedimentary rocks.

Large oil fields occur in altered intrusive and extrusive rocks in the "serpentine" fields of central Texas, the oil production of Cuba comes from similar rocks, and the Furbero oil field of Mexico is in altered intrusive gabbro. Most of the serpentine of the serpentine fields of Texas has proved to be hydrated tuff, breccia, and ferromagnesian types of lava from volcanic extrusions contemporaneous with Upper Cretaceous sedimentation, similar in origin to the exposed masses of igneous rock in the same region. Some of the serpentine of Cuba is known to have been derived from olivinitic rocks and most of it is believed to represent altered intrusive rock. The Conejo oil field, California, produces from basalt agglomerate.

Occurrence of solid bitumens, such as crystals and small balls of thucolite, are known in granites, gneisses, and pegmatite in eastern Canada, Norway, Sweden, England, Germany, Russia, and elsewhere. Graphite may be formed by metamorphism of hydrocarbons, and occurrences in Virginia, New York (?), Brazil, and Peru are thought to represent the final products of metamorphism of oil.

Bitumens are found in many metal mines and gas in a few. In most places there is nothing unusual about the occurrences because the mineralized area is in sedimentary rocks. However, a number of examples of bituminous matter associated with mineral deposits, and especially with cinnabar and vanadium ores in igneous or metamorphic rocks, are given

in the list of minor occurrences at the end of this symposium. Migration of petroleum has been downward through joints or fissures.

No major oil fields can be formed in igneous rocks intruded into sedimentary rocks, because of the limited reservoirs produced by such intrusions and because of the limited amount of oil distilled from adjacent petroliferous beds, as the chilling effect of the country rock soon cools an intrusion of small size. Doming of reservoir rocks in overlying sedimentary rocks caused by laccolithic intrusion, as at Furbero, Mexico, creates an anticlinal structure in which oil may accumulate, but, here also, the structurally closed reservoirs are small areally. Large oil fields can occur only in the eroded and altered surface of igneous and metamorphic rocks at the unconformable contact under petroliferous sedimentary rocks. Accumulation of large quantities of oil can be expected only in buried hills and ridges in the older rocks where a considerable section of the source rocks is in contact with the reservoir.

SUMMARY

(SIDNEY POWERS)

Oil and gas fields can occur in igneous rock only when that rock has had porosity developed by metamorphism, alteration, and brecciation. Generation of petroleum by distillation of organic matter in the sediments adjacent to the igneous intrusion or extrusion may be a contributing factor. The contact zone between the igneous and sedimentary rocks may furnish a channel for migration. Almost all of the igneous rocks in which, or correlated with which, petroleum is found are ferromagnesian.

Petroleum is found associated, in order of importance, with laccoliths, extrusive fragmental rocks, such as tuffs and breccias, and with dikes, plugs, and sills. Laccoliths and tuff or ash cones arch the overlying sedimentary rocks into anticlinal structure which will be favorable for petroleum accumulation.

All of the petroliferous provinces in the world are marked by surface indications of petroleum such as seepages of oil or gas or deposits of bituminous matter, ordinarily as asphalt, in some places as the solid bitumens grahamite, albertite, or thucholite.

Seepages of oil around the volcanic plugs at Cerro de la Pez and Cerro de la Dicha led to the discovery of the Ebano field, Mexico. Seepages of oil and vesicles filled with oil in the dikes of southwestern and southern Colorado prove the petroliferous character of rocks in the stratigraphic section and commercial deposits of oil and gas have been found in them. Seepages associated with dikes and sills in the Karoo

series of South Africa, in the Triassic rocks of Brazil, and in Eocene rocks in New Caledonia, indicate that oil may be found in commercial quantities in those areas.

Oil and gas are also found as traces of bitumen, as seepages, and as commercial deposits at and, in places, beneath the eroded surface of igneous and metamorphic rocks. Traces of bitumen, in some places indistinguishable from indurated carbonaceous material, are found in the pre-Cambrian rocks of New York state and the province of Ontario, Canada, in the granites of Colorado, Wyoming, England, and Scotland, and in gneisses in Norway, Sweden, Scotland, and elsewhere.

Seepages occur in granite in Colorado and Wyoming, and very large seepages occur in schist at Torondoy, Venezuela. The oil which issues as seepages along the Front Range of the Rocky Mountains in pre-Cambrian granite, quartzite, and other rocks is evidently derived from petroliferous rocks, probably of Cretaceous age, under overthrust faults. Commercial oil fields may be developed along the boundary of the United States and Canada in the younger rocks under the low-angle fault planes which have moved the quartzites of the Belt terrane from 50 to 100 miles eastward over younger rocks.

Important oil and gas fields are associated with the weathered and altered surfaces of basement igneous and metamorphic rocks, especially where these rocks stood as topographic hills during the deposition of the overlying sedimentary rocks and now form buried hills and mountains. The leading example is the gas and oil above the Amarillo Mountains, the buried western extension of the Wichita Mountains, whose submerged granite peaks extend from Sayre, Oklahoma, past Amarillo, Texas, 80 miles. The Amarillo gas field is the largest developed gas reserve, both in volume and area, in the world.

CLASSIFICATION OF OCCURRENCES

(FREDERICK G. CLAPP)

Some sort of classification should be held in mind while discussing occurrences of oil associated with any kind of rock; therefore, the writer finds it necessary to quote a portion of his structural classification, first proposed in 1910[1] and revised in 1917.[2]

[1]Frederick G. Clapp, *Eng. Soc. W. Pennsylvania*, Vol. 26 (1910), pp. 87-120; also in paper read before *Geol. Soc. Washington*, March 9, 1910; Abstract, *Science*, Vol. 31 (1910), pp. 718-19; *Econ. Geol.*, Vol. 5 (1910), pp. 503-21.

[2]*Idem*, "Revision of the Structural Classification of Petroleum and Natural Gas Fields," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 553-602.

That part of the classification pertaining to the association of oil with igneous intrusions, was first proposed in part by DeGolyer[1] in the first five headings in the following list. The present writer has added the last four classes of occurrence to the table.

SEEPAGES ASSOCIATED WITH ROCKS OF IGNEOUS ORIGIN

(a) Contact of volcanic plugs and sedimentary rocks
(b) At contact zones of dikes and sedimentary rocks
(c) Cracks and fissures in the igneous rock itself
(d) Inclusions (vesicles, amygdules) in the igneous rock
(e) Metamorphosed rock above an intrusion which does not crop out
(f) Contact of a sill or laccolith with sedimentary rocks
(g) Lava flows or tuffs, or ash beds, or at their contact with sedimentary rocks
(h) Domes formed by laccoliths
(i) Residual bitumens above or from pre-existing igneous rocks

It may be in order here to correct errors that are now known to exist in previous writing. Figure 12 in the revised classification paper[2] is now known to be correct only as regards its surficial aspect, for volcanic necks have been found not to descend outward beneath the surface at similar angles to their surficial inclinations, as supposed prior to thorough drilling of oil fields in the "Golden Lane" of Mexico.

Huntley[3] states that "Wells drilled close to the contact of several of these conical hills have disproved the theory...that they were 'plugs' whose conical shape persisted at depth." The wells at Juan Casiano, Mexico, are not believed by DeGolyer[4] to be due to the proximity to a plug, though they are only 700 to 2,000 feet distant from it, and the conditions are similar to the New Zealand occurrence. Huntley's theory of occurrence is depicted in Figure 4 of his original paper, whereas a map of the relations of the principal intrusions to oil accumulation is given in Figure 6 of his paper. "Mushrooming" of the necks had been previously postulated and diagrammed by Garfias.[5] There is no doubt that some oil does exist against, and in the crevices of, volcanic necks, but it has accumulated in commercial or semi-commercial quantity only where the individual necks correspond with folds or with fault structures.

[1]E. DeGolyer, "The Effect of Igneous Intrusions on Accumulation of Oil in the Tampico-Tuxpam Region, Mexico," *Econ. Geol.*, Vol. 10 (1915).

[2]Frederick G. Clapp, "Revision of the Structural Classification of Petroleum and Natural Gas Fields," p. 586.

[3]L. G. Huntley, "The Mexican Oil Fields," *Trans. Amer. Inst. Min. Eng.*, Vol. 52 (1915), p. 309.

[4]*Econ. Geol.*, Vol. 10 (1915), p. 660.

[5]V. H. Garfias, "The Effect of Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico," *Jour. Geol.*, Vol. 20 (1912), pp. 666-72, figs. 1-3.

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NATURAL GAS, SALT, AND GYPSUM IN PRE-CAMBRIAN ROCKS AT EDWARDS, NEW YORK[1]

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Edwards, New York

ABSTRACT

Non-commercial quantities of inflammable gas were found in small vugs and fractures in metamorphosed Grenville (pre-Cambrian) magnesian limestone in the 900- and 1,500-foot levels of the zinc mine at Edwards, St. Lawrence County, New York. The most significant minerals found in the openings containing the gas are salt and gypsum. The geological evidence seems to suggest a natural organic derivation similar to that of commercial accumulations in younger rocks.

INTRODUCTION

Edwards is a small village in the town of Edwards, St. Lawrence County, northern New York. It is about 15 miles east of Gouverneur, a larger village, which has been for many years the seat of a small marble quarrying industry. The region between Edwards and Gouverneur has long been one of the chief localities in the United States for the production of fibrous talc.

Zinc ore was discovered near Edwards village about 1903, but was not produced commercially until 1915. Since that year production has been continuous and a somewhat remarkable mine of moderate size has been developed. It is in this mine that the unusual showings of gas, salt, and gypsum occur which are the subject of this paper.

ACKNOWLEDGMENT

The writer is indebted to C. A. Hartnagel, assistant state geologist of New York, at Albany, for revision of the manuscript, and to F. H. Lahee, K. C. Heald, R. W. Clark, P. D. Trask, H. D. Miser, M. I. Goldman, and J. C. Reed, for helpful criticism.

[1]Manuscript received, April 8, 1932. This paper was solicited by C. A. Hartnagel at the request of Sidney Powers.

[2]Geologist, St. Joseph Lead Company.

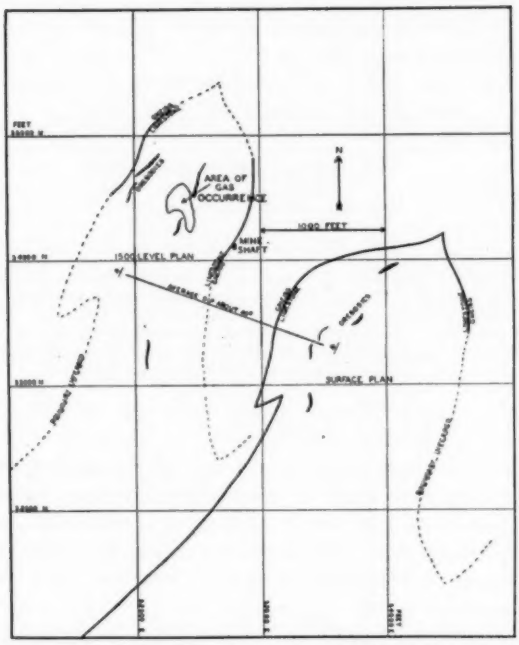

FIG. 1.—Surface plan of the Edwards zinc mine showing local details of folding.

REGIONAL GEOLOGY[1]

Pre-Cambrian crystalline rocks underlie the entire region. They are covered to a greater or less extent by glacial deposits. Thin remnants of Potsdam sandstone also rest on the crystallines at places, and, presumably, the region once was covered by a considerable thickness of the lower Paleozoic rocks, which are still present on the west and south-

[1]The most important reports published on the geology of this region are the following.

D. H. Newland, "Zinc-Pyrite Deposits of the Edwards District, New York," *New York State Defense Council Bull. 2* (1917).

C. H. Smythe, Jr., "Genesis of the Zinc Ores of the Edwards District, St. Lawrence County, New York," *State Mus. Bull. 201* (1917).

H. P. Cushing and D. H. Newland, "Geology of the Gouverneur Quadrangle, New York," *State Mus. Bull. 259* (1925).

C. H. Smythe, Jr., and A. F. Buddington, "Geology of the Lake Bonaparte Quadrangle, New York," *State Mus. Bull. 269* (1926).

A. F. Buddington, "Granite Phacoliths and their Contact Zone in the Northwest Adirondacks, New York," *State Mus. Bull. 281* (1929), pp. 51-107.

west. A great erosional and angular unconformity intervenes between the pre-Cambrian and the Potsdam. The Paleozoic rocks, in the writer's opinion, have no bearing on the occurrence of gas, salt, or gypsum.

The pre-Cambrian rocks belong to two major classes: (1) metamorphosed sediments commonly referred to the Grenville, and (2) igneous rocks intrusive into the Grenville. The principal igneous rocks of the area in the order of intrusion are (a) hornblendic gabbro, (b) syenite, and (c) granite, probably of two ages.

The Grenville may be separated lithologically into two natural divisions, limestone and gneiss. The limestone, commonly, is a thoroughly recrystallized magnesian variety or dolomite. The gneiss represents the siliceous and aluminous sediments plus a large amount of igneous injected matter. It includes altered quartzite and a large variety of feldspar-biotite-garnet-pyroxene rocks. The Grenville, both gneiss and limestone, at many places contains a little graphite.

The limestone is the depository for all the zinc ores, which, on fairly certain grounds, are believed to be of pre-Cambrian age, probably originating as the end product of the igneous activity.

The ore forms irregular lenses in the limestone, ordinarily not of great thickness or width, but of remarkable persistence on the dip; individual lenses at Edwards have been mined from the surface to a vertical depth of 1,500 feet down an average dip of about 40°. It is in the limestone enclosing these zinc "veins" that the gas is found.

The limestone has been extensively altered by the solutions from the various intrusives, the commonest alteration minerals being tremolite and diopside and their respective further derivatives, talc and serpentine. The alteration varies greatly in local intensity and there are many areas of relatively pure crystalline magnesian limestone and others of intense silicification. In addition, the limestone members contained originally considerable intercalated white quartzite or siliceous limestone and these bodies remain as more or less modified siliceous masses.

Structurally the area is one of complex folding closely related to the various intrusives, and the folds commonly are overturned so that the dips on either flank are to the northwest, ranging generally between 30° and 60°. The trend of folds and formations normally is northeast-southwest. Extreme compression has resulted in much differential flowage and adjustment in the Grenville beds, especially in the limestone which has generally been molded into any convenient shape that would accommodate the more resistant gneisses and the invading magmas. The apparent bedding in limestone is generally flow banding rather than

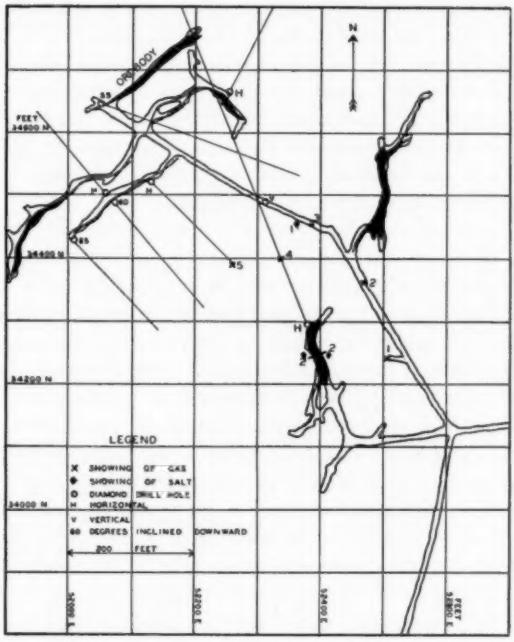

FIG. 2.—Plan of the Edwards zinc mine at the 1,500-foot level.

true bedding, although in general it represents to some degree the true folded structure of the masses. To a considerably greater extent the present cleavage of the gneisses corresponds with the original bedding, and taken in conjunction with areal distribution, a great deal of excellent structural detail can be deciphered in the region.

LOCAL GEOLOGY

The Edwards mine is in a limestone mass which lies inside the curve of a well defined hook-shaped fold, one limb of which is well exposed for miles, but the other for the most part concealed except at the curve. The enclosing limbs are formed by a band of Grenville gneiss which can be briefly described as a granitized quartzite. Since the Grenville limestone has commonly been regarded by geologists working in this area as constituting synclinal remnants resting on a basement of Grenville crystallines, it is natural that this hook-shaped fold has been inter-

preted as the nose of a closely compressed overturned syncline. From a regional study of the related structures near Edwards, however, the writer is convinced that this is not the fact, but that the hook-shaped fold is merely a minor anticlinal warping on the side of a much larger, overturned, dome-shaped anticlinorium. The local details of the fold and the location of the mine are shown in Figure 1. It will be noticed that the dip of the axial plane of the fold is nearly parallel with the dip of the beds, due, probably, to steepening from excessive flowage parallel with the dip.

DETAILS BEARING ON OCCURRENCE

Topography.—The surface around the mine averages about 700 feet above sea-level, with a relief of about 100 feet. Some of the ore bodies crop out on a low limestone ridge that occupies part of the interior of the hooked fold. Others, however, are concealed by an extensive silt and sand deposit, one of the typical plains of assorted glacial outwash. This plain is traversed by the Oswegatchie, a considerable river. The thickness of silt and sand is known from borings to range from 100 to 175 feet, so that the pre-glacial Grenville surface has a relief of nearly 300 feet.

Mine water.—Almost from the beginning the mine has yielded a considerable flow of water averaging approximately 500 gallons per minute. In every level down to 1,200 feet, water has issued at different places, the bulk of it always from open solution cavities generally in the vicinity of some one of the ore bodies. With complete development of the 1,500-foot level, no water has been encountered except a very small drip from some tight fractures near the limestone-gneiss contact, indicating that the solution channels either no longer exist or have deviated from the known ore bodies. The writer is inclined to regard the solution cavities as the work of normal ground water, though this may be open to question. It is certain, however, that the mine water is entirely of surface origin. It exhibits seasonal fluctuations which vary with the local precipitation and shows a distinct connection with Oswegatchie River. Moreover, it is an ordinary hard water such as normally comes from channels in limestone.

Oxidation.—The ore bodies for several hundred feet below the surface show slight oxidation effects, generally in the vicinity of the water courses. Such oxidation is entirely lacking below the 1,300-foot level.

Faulting and fracturing.—Fractures as well as faults of small displacement, later than the folding and ore formation, are common in the mine. Most of the stronger fractures dip steeply, those with evident

displacement being generally nearly vertical. They trend in different directions. The maximum observed displacement is about 10 feet, but ordinarily it is not more than a foot or two, and in many cases a mere fraction of an inch. Smaller fractures within or very near the ore bodies and roughly parallel with them in strike and dip also are abundant. These fractures commonly are filled by seams, as large as ½ inch thick, of cementing material, which in some cases is plain calcium carbonate, in others serpentine or tremolite or a derived asbestos matter, and in still others gypsum. The possible significance of the gypsum will be mentioned later.

Many of the fractures on the upper levels are sufficiently enlarged to form minor water courses and the fillings have been dissolved or washed away. On the lower levels they are tight and dry except as previously noted.

DESCRIPTION OF MINERAL OCCURRENCES

Gas occurrence.—Figure 2 shows the details of the mine on the 1,500-foot level, approximately 800 feet below sea-level, where the gas and salt are found. The gas was encountered entirely in drilling. Showings 1, 2, and 3 were from holes 6 or 8 feet deep drilled for blasting. Only weak flows which would burn momentarily were obtained. Showing 4, encountered in a horizontal diamond-drill hole, burned feebly for a day or two. Showing No. 5, also in a horizontal diamond-drill hole, was the strongest. The drill hole, about 1 inch in diameter, was plugged and fitted with a ¼-inch pipe and valve. The gas showed considerable pressure and was allowed to burn steadily for several days to prevent its accumulation in the workings. The flame rose about a foot in height. The gas was lighter than air and had a slight but not unpleasant odor. After about a week its pressure diminished so that it would not burn continuously. The valve now is kept closed, but when it is opened the gas still burns for a few minutes, although it is several months since the hole was drilled.

During the period of strong flow, a sample of the gas was collected for analysis. The sample was taken in an acid carboy which had been cleaned, filled with water, rubber stoppered and fitted with two glass tubes. The gas was first allowed to bubble through the water for 20 minutes in order to saturate it with any soluble constituents. The carboy was then inverted and the gas allowed to expel the water, after which it was sealed.

The following analysis was obtained through arrangement with Professor C. P. Berkey, of Columbia University; it was made under the direction of Professor J. J. Morgan, of the chemistry department of that institution.

Analysis of gas (per cent by volume)	*Per Cent*
Hydrogen sulphide, H_2S	0.0
Carbon dioxide, CO_2	0.0
Illuminants (unsaturated hydrocarbons)	0.0
Oxygen, O_2	0.2
Hydrogen, H_2	0.6
Carbon monoxide, CO	0.0
Ethane, C_2H_6	0.7
Methane, CH_4	59.1
Nitrogen, N_2 (by difference)	39.4
	100.0

Professor Morgan states: "The sample appears to be a low grade natural gas with a heating value of approximately 600 B. T. U. per cubic foot."

The rocks in the vicinity of the gas occurrences in both the drift and the drill holes are tight and unfractured. To the eye they consist mainly of light or white limestone considerably modified by silicification, particularly at the two places in the diamond-drill holes from which the gas issued. Serpentine, which is typical near the ore, is absent or sparing in this area. A thin section from the core of a drill hole at some distance from the gas consists of about 60 per cent carbonate (presumably dolomite) enclosing scattered grains of diopside.

Salt occurrence.—The occurrence of salt is almost as surprising as that of the gas and since both are found in such close proximity the idea of a genetic relationship naturally is suggested. Occurrence No. 1 is in a small vug or open cavity about 2 inches in diameter enclosed in solid rock, a light silicificated dolomitic limestone. The vug is lined with a thin incrustation of calcium carbonate, and inside this, filling about half the cavity, is an irregular mass of clear crystallized halite.

Occurrence No. 2, quite different, is in a slight post-ore fracture which crosses a body of massive ore, zinc and iron sulphides. The fracture is 3 or 4 feet long horizontally, about ¼ inch wide, and seems to tighten and disappear at either wall of the ore. It dips about 30° north. The fracture is partly filled by calcium carbonate and asbestos-like matter, but the most abundant material is white crystalline halite. This, therefore, is clearly a deposit from solution and later than the ore formation. However, it is conceivable that it may represent the re-

distribution by post-ore solutions of salt originally contained in the country rocks of the vicinity.

Gypsum occurrence.—Gypsum has been mentioned as a common fracture filling in and near the ore bodies on the lower levels. Presumably it was equally abundant in the higher levels, but has been mostly removed in the enlargement of the cracks by solution due to ground waters of surface origin. It has been observed at places from the 900- to the 1,500-foot levels and in association with several of the ore bodies, so that its distribution is general. It is somewhat uncommon at a distance from the ore bodies, but filled fractures also are less common. Indeed, it seems possible that many of the minor fractures, especially those paralleling the ore, arose through shrinkage and settling in the process of replacement of limestone by ore.

Where the fractures are filled by sepentine, talc, tremolite, or asbestos, it seems clear that these are merely crushed wall rock, more or less altered. They are in many places slickensided by movement. The carbonate fillings, in part, are similar. The carbonate, in part, and the gypsum, entirely, are fillings deposited from solution, presumably in parts of the fractures that remained open. The common variety of gypsum is fibrous with the fibers elongated across rather than parallel with the fracture planes.

The conclusion regarding gypsum is that it probably originated from chemical action upon limestone of post-ore mineral waters charged with sulphuric acid, and that these solutions long antedated the present ground waters, and probably followed closely the period of ore formation. From the similarity of occurrence, it is possible that a similar explanation applies to the salt.

CONCLUSIONS

The writer has had no opportunity to compare the analysis of this gas with that of natural gas from other localities, nor does he feel qualified to discuss the possibility that it may have originated as a chemical rather than an organic product. The geological evidence seems to suggest a natural organic derivation essentially similar to that of the extensive commercialized accumulations in younger rocks. The fact that several separate occurrences, no one of which drained the others, have been tapped, indicates the existence of small isolated pockets now sealed from each other, but perhaps originally connected. The host rock appears to have been an impure member in the limestone, now broken apart and its fragments sealed securely by the surrounding purer and more plastic

limestone. The occurrence of the salt possibly evidences the presence of a common associate of oil and gas, although this may be questioned, in view of the different explanation which seems preferable for gypsum.

It may perhaps be well to emphasize that the writer does not regard the occurrence of the natural gas as of any but scientific interest, for it is scarcely conceivable that an accumulation of commercial importance could be preserved in rocks as highly metamorphosed as those of this locality. Nevertheless, it suggests the possibility that if some place could be found where favorable reservoir rocks of pre-Cambrian age had not suffered excessive deformation, economic deposits of gas might still be expected in them. It also adds interest to the speculations on life and processes in the pre-Cambrian. Perhaps conditions may not have differed so greatly from those of the succeeding era as we have been prone to believe.

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VOL. 16, NO. 8 (AUGUST, 1932), P. 736

POSSIBLE ORIGIN OF GRAPHITE IN SOME ANCIENT QUARTZITES, SLATES, AND SCHISTS, IN VIRGINIA[1]

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ABSTRACT

Graphite which occurs in the lower Paleozoic metamorphosed sedimentary rocks in the Appalachian Mountains is believed to represent the final stage of metamorphosed petroleum.

That graphite is found in ancient rocks of sedimentary origin is well known to all observing geologists who have had opportunity to study such rocks. In the old Appalachians of the eastern part of the United States graphitic quartzites, slates, and schists are very common, ranging in age from Ordovician to Cambrian and perhaps older.

Twenty years ago, while investigating the slate deposits of Virginia for the Virginia Geological Survey, the writer collected many specimens of dark graphitic quartzite associated with and bedded with slates and sericite schists, many of which were more highly graphitic than the quartzite.

These quartzites, as seen in thin sections under a petrographic microscope, are normal. The interstices between the rounded sand grains were completely filled with secondarily added silica, and the secondary silica was very uniformly impregnated with small particles of graphite. The wide distribution of the graphitic particles in the secondarily added silica, and the close relation of these quartzites with graphitic sericitic schists and slates, strongly suggest that these quartzites may be fossil oil sands and the slates and schists the metamorphic equivalents of the mother shales. Such quartzites and associated schists and slates are found in the old Appalachians all the way from New York to Alabama and have been mined for their graphite content.

Undoubtedly such deposits are common where old sediments occur. The graphite in these beds suggests the metamorphic residue of petroleum.

[1]Manuscript received, June 27, 1931.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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BITUMEN IN NONESUCH FORMATION OF KEWEENAWAN SERIES OF NORTHERN MICHIGAN[1]

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ABSTRACT

In the Upper Peninsula of Michigan in the southwest part of Keweenaw Point bituminous matter is found in the Nonesuch formation of upper Keweenawan age. This formation consists largely of shale, the bituminous matter being found in the interbedded sandstones, where it is closely associated with native copper and chalcocite.

LOCATION

In the vicinity of the Porcupine Mountains of northern Michigan, in T. 50 N., R. 42 and 43 W., beds in the lower part of the Nonesuch formation have been exploited for copper at the White Pine, White Pine Extension, and Nonesuch mines. A coal-like bitumen is found here as a cement in some of the sandstone beds and in fractures and fissures associated with cross faulting.

STRATIGRAPHY

The Keweenawan series of Michigan is divided into the upper, middle, and lower Keweenawan.[3] With the exception of a large part of the Nonesuch formation, which is distinctive because of its dark gray to black color, the sedimentary rocks of the Keweenawan are red. The middle and lower divisions of the Keweenawan include ferromagnesian types of lava flows, intrusive and extrusive felsites, and other igneous rocks. No igneous rocks are present in the upper Keweenawan.

The upper Keweenawan consists from top to bottom of the Freda sandstone, the Nonesuch formation, and the Outer (Copper Harbor) conglomerate (Fig. 1).

Freda sandstone.—According to Lane,[4] the Freda sandstone consists of red beds, "generally a red, impure sandstone, sometimes conglomeratic

[1]Read by title before the Association at the San Antonio meeting, March 21, 1931. Manuscript received, April 23, 1931.

[2]Consulting geologist, 702 National Bank of Commerce.

[3]C. R. Van Hise and C. K. Leith, "The Geology of the Lake Superior Region," *U. S. Geol. Survey Monogr. 52* (1911), pp. 366-67.

[4]A. C. Lane, "Keweenaw Series of Michigan," *Michigan Geol. Survey Pub. 6, Geol. Ser. 4*, Vol. 1 (1911), p. 40.

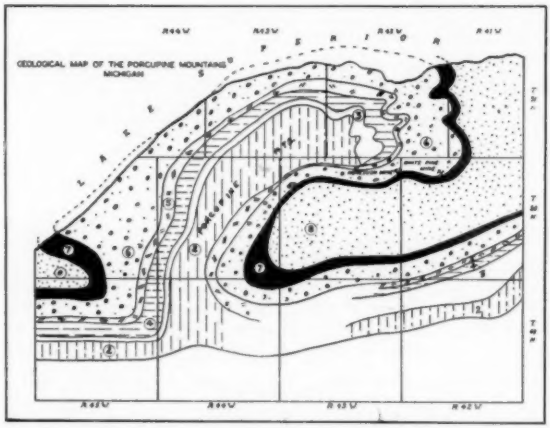

FIG. 1.—Geological map of Porcupine Mountains, Michigan; 17 × 24 miles.
KEWEENAWAN SERIES
Lower division
2, Quartz porphyry and felsite; *3*, diabase, diabase amygdaloid, melaphyre, and diabase porphyry with one porphyry conglomerate; *4*, sandstone and conglomerate; *5*, diabase, diabase amygdaloid, and melaphyre
Upper division
6, Sandstone with thin bands of conglomerate; *7*, dark gray sandstone and black shale (Nonesuch); *8*, red sandstone (Freda)
(From R. D. Irving, "The Copper-Bearing Rocks of Lake Superior," *U. S. Geol. Survey Monogr. 5*, 1883.)

and sometimes red shale, in general much like the Outer and Great conglomerate, except that the conglomerate becomes less and less abundant."

Nonesuch formation.—The Nonesuch formation in the Porcupine district, according to Lane, has a thickness of 600 feet.

The Nonesuch forms a distinct sedimentary unit in the Keweenawan section because of (1) its dark color, (2) its content of bituminous matter, and (3) the presence of finely disseminated native copper and fissure deposits of native copper and copper sulphides.

Lithologically, the Nonesuch is in major part dark gray to black shale, which contains interbedded brown and greenish gray sandstones, grits, and fine-grained conglomerate. Lane states that the formation "preserves, beautifully, ripple marks and mud cracks, and seems also to contain traces of crawling animals or sea weed."

The dark color of the Nonesuch is due to the presence of chlorite, bituminous matter and the large amount of ferromagnesian types of detritus.

Outer (Copper Harbor) conglomerate.—Irving[1] estimates the thickness of the red sandstones and interbedded conglomerate at 3,000 feet. The sandstone predominates over the conglomerate, the latter being present as irregular bands.

MODE OF OCCURRENCE OF BITUMEN

The bituminous matter in the Nonesuch formation is found as a cement in sandstone beds of this formation and in the fractures and fissures related to cross faulting. Figure 2 shows the bitumen filling the interstices between the mineral and rock grains in a sample of Nonesuch sandstone. Pieces weighing as much as 20 pounds, composed largely of bitumen, have been obtained from cross faults at the White Pine and White Pine Extension mines.[2]

Much of the disseminated bitumen is closely associated with native copper, much of the bitumen being surrounded by copper. The copper replaces the chlorite fringe around the bitumen; it also replaces part of the adjacent mineral or rock grains. The bitumen, therefore, was present in the Nonesuch beds prior to the deposition of the copper.

Bitumen is present in the Nonesuch beds where there are no copper values.

The maximum amount of bituminous cementing material is about 2 per cent.

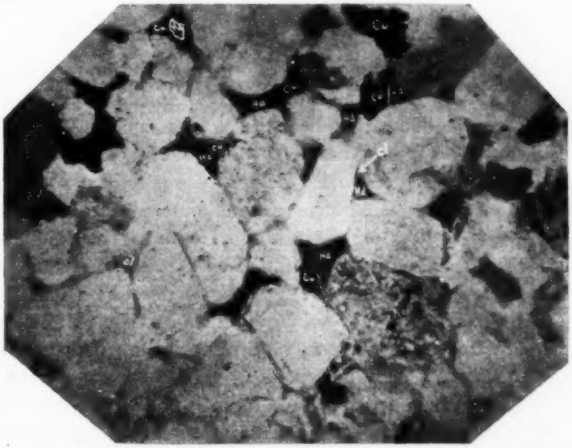

FIG. 2.—Microphotograph of Nonesuch sandstone. *Hd*, bitumen; *Cl*, chlorite; *Cu*, native copper. In upper left corner note bitumen surrounded by native copper.

[1]R. D. Irving, "The Copper-Bearing Rocks of Lake Superior," *U. S. Geol. Survey Monogr. 5* (1883), p. 220.

[2]Tom Broderick, geologist, Calumet and Hecla Copper Company, personal communication.

The chlorite occurs as a fringe between the bitumen and the adjacent mineral or rock grains. No bitumen was noted without this association of chlorite.

No bitumen is found in the red sandstone beds in or outside of the Nonesuch formation.

PHYSICAL PROPERTIES AND CHEMICAL ANALYSIS OF BITUMEN

The bitumen in the Nonesuch formation has a hardness of about 2, is coal-like in appearance, shows a conchoidal fracture, and is infusible in a closed tube before the blowpipe. It is slightly soluble in carbon tetrachloride and insoluble in hydrochloric acid and aqua regia.

Nishio[1] gives the following analysis of the bitumen.

	Per Cent
Volatile matter	2.4
Carbon (fixed)	64.8
Ash	33.3
	100.5

According to another analysis by Nishio the volatile matter contains 5.35 per cent hydrogen. The writer has not available any complete analysis of the ash. Nishio reports the ash to contain about 2 per cent copper.

In the classification by Abraham[2] the Nonesuch bitumen fits closely his description of asphaltic pyrobitumens.

ORIGIN OF BITUMEN

The black shales of the Nonesuch formation appear to be the most probable source material of the bitumen. These shales are bituminous and yield a tarry distillate when heated in a glass tube.

The bitumen, as it now exists, is a metamorphosed product, high in fixed carbon and free from oxygenated compounds. The bitumen at one time must have had sufficient mobility to penetrate the fissures and sandstone interstices where it is now found. The change to its present state could have occurred in part by slow and continued oxidation, just as some asphaltites of the type of grahamite have been formed.

Whether the bitumen was originally formed by the heat and pressure connected with the metamorphism of the region or whether it existed prior to this metamorphism, is difficult of proof. Admitting the possibility of its formation during metamorphism, the writer believes that the bitumen was present as asphaltic material before this change and that the metamorphism along with continued oxidation produced the bitumen as now found.

[1]Keijiro Nishio, *Econ. Geol.*, Vol. 14 (1919), pp. 324-34.

[2]Herbert Abraham, *Asphalts and Allied Substances*, 3rd ed. (1929), p. 195.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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OIL FIELDS IN IGNEOUS ROCKS IN COASTAL PLAIN OF TEXAS[1]

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ABSTRACT

Oil produced in commercial quantities from igneous rock in the Cretaceous formations of the Gulf Coastal Plain of Texas is obtained from eight fields as follows: Thrall, Chapman, Yoast, Lytton Springs, Dale, Buchanan, Lytton Springs townsite, and Schimmel-Batts. Showings of oil in igneous rock have been found at several other localities. The rock containing the oil was originally basaltic in character, but has been changed by alteration to chlorite or serpentine. It is probably largely extrusive in origin, but may be, in small part, intrusive. Porosity is present in variable amounts and production is irregularly distributed in each field, many dry wells offsetting good producers. Initial production varies from a few to 5,000 or more barrels. The igneous rock in the producing fields lies chiefly at or near the base of the Taylor marl. The oil is of paraffine base and high gravity, usually 38°-39° Bé., although in one field it is as low as 27° Bé. It is accompanied usually by very little water. Drilling is by rotary tools and largely through soft formations. Ultimate production to the acre will range in different fields from 1,200 to 10,000 barrels.

INTRODUCTION

The Thrall oil field in Williamson County, Texas, was discovered in 1915. Early in the history of this field it was shown by J. A. Udden that the oil was obtained from igneous rock.[3] Since that time commercial production has been obtained in the Gulf Coastal Plain of Texas from igneous rock in seven additional fields as well as showings of oil from igneous rock in a number of other localities. These occurrences of oil are entirely within the Cretaceous formations. Pyroclastic rocks and serpentine occur in the Gueydan formation of the Texas Coastal Plain, but no oil has been produced from them.[4]

Of the known igneous rock masses in the Texas Coastal Plain the greater number are exposed at the surface and do not contain oil. In

[1]Manuscript received, July 20, 1931.

[2]Director, Bureau of Economic Geology, University of Texas.

[3]Johan A. Udden, "Thrall Oil in Serpentine," *Oil and Gas Journal*, Tulsa, Oklahoma, April 22, 1915; "Oil in Igneous Rocks," *Economic Geology*, Vol. 10 (1915), pp. 582-85.

[4]Thomas L. Bailey, "The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas," *Univ. Texas Bull. 2645* (1926).

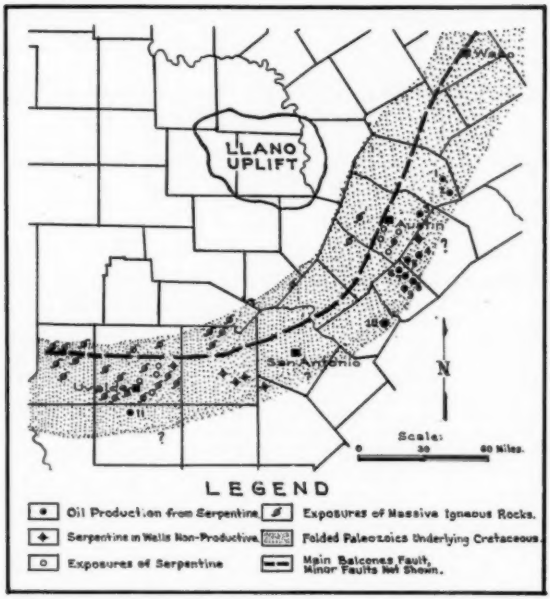

FIG. 1.—Map showing location of igneous rocks along Cretaceous outcrop in Texas and their relation to Balcones fault zone and belt of folded Paleozoic rocks underlying Cretaceous. Localities indicated on map and described in text are: 1, Thrall; 2, Chapman; 3, Kimbro; 4, Yoast; 5, Schimmel-Batts; 6, Lytton Springs townsite; 7, Lytton Springs; 8, Dale; 9, Buchanan; 10, Darst Creek; 11, Zavala County.

1927 Lonsdale was able to list 73 localities showing massive igneous rocks at the surface and one locality where such rock had been located in drilling.[1] In the same publication 20 or more occurrences of altered igneous rock, serpentine, or chlorite are listed, of which 8 are from surface exposures and 12 are underground. Since that time wells have encountered serpentine or basalt, several being located in Zavala County.

Commercial oil fields in serpentine in the Texas Coastal Plain are Thrall, Chapman, Yoast, Lytton Springs, Dale, Buchanan, Lytton Spring townsite, and Schimmel-Batts. Showings of oil have been found at several other localities. In this article fields described previously are briefly mentioned and new occurrences of commercial value are more fully described.

[1] J. T. Lonsdale, "Igneous Rocks of the Balcones Fault Region of Texas," *Univ. Texas Bull. 2744* (1927).

ACKNOWLEDGMENTS

In the preparation of this paper the writer has been permitted to make use of notes assembled by F. H. Lahee, D. M. Collingwood, and F. M. Getzendaner. Data on production have been obtained from the United States Bureau of Mines, The American Petroleum Institute, the *Oil Weekly*. The production figures given in the text and records of certain wells in the Darst Creek and Lytton Springs areas were very kindly furnished by Wallace E. Pratt of the Humble Oil and Refining Company. Well records have also been furnished by the Gulf Production Company. The contour map of the Dale field has been made by J. M. Hancock, who has also supplied notes on this field. The map and section of Lytton Springs were furnished by F. H. Lahee.

CHARACTER OF IGNEOUS ROCK

Igneous rocks are found in the Gulf Coastal Plain between the Mexican border and the central part of the state and occur in formations ranging in age from the Eagle Ford to the latest Cretaceous.[1] These include massive, relatively unaltered rocks which are chiefly, though not entirely, basaltic in character; and more or less altered rocks commonly referred to as serpentine. In detailed studies Lonsdale[2] has shown that the massive igneous rocks include olivine basalt, nephelite basalt, nephelite-melilite basalt, limburgite, gabbro, phonolite, and nephelinite. The serpentinized rock appears to represent in large part basaltic rock altered after extrusion, although in places, as in the vicinity of Austin and near Lytton Springs and at a number of localities in the Uvalde region,[3] it was derived from re-worked igneous rock now embedded in a sedimentary formation.

In general the massive and altered rocks are associated, although the serpentinized rocks lie chiefly coastward from the massive rocks (Fig. 1). The igneous rocks discovered in drilling are almost entirely serpentine. Lonsdale noted a few localities in Uvalde County where the altered igneous rock lies around, and is obviously derived from, the massive. The massive rock, according to him, includes stocks, plugs, sills, and dikes, which are largely, if not entirely, intrusive. Getzendaner, however, is of the opinion that the massive rock was extruded during Cretaceous time, subsequently covered by sediments, and has now been

[1]Serpentine has been found in Bastrop County in the Georgetown-Edwards, but occurrences within the Lower Cretaceous are exceptional.

[2]J. T. Lonsdale, *op. cit.*

[3]T. W. Vaughan, "Uvalde Folio," *U. S. Geol. Survey Folio 64* (1900).

uncovered by erosion.[1] The origin of the serpentinized rock from which commercial production of oil has been obtained is not obvious in all cases. Some of these occurrences, as at Thrall, can be shown to have been largely if not entirely extrusive.[2] On the other hand, it has been suggested that some of the serpentine masses may be in part extrusive and in part intrusive.[3]

RELATION OF IGNEOUS ROCKS TO REGIONAL GEOLOGY

The Cretaceous formations in which the igneous rocks are found include limestones, marls, shales, and some sands tilted into an eastward dipping homocline. The rocks of this system increase rapidly in thickness eastward by the addition of both new members at the base and younger formations at the top. In central Texas these formations are cut at the outcrop by the Balcones zone of faulting. West of this zone the eastward dip is a few feet per mile. In and east of the fault zone the dip is steeper, ranging from 50 to 200 feet per mile (1° to 4°).

A stratigraphic section of Eocene and Cretaceous formations is given for the area where igneous rocks occur. The section varies in lithology and thickness along the strike and down the dip and the formation thicknesses are only approximate. In general the section thickens toward the Gulf and toward the Rio Grande embayment. The Escondido formation of the Uvalde region is not regarded as the exact equivalent of the Navarro, and is in part younger.

The European equivalent of the Texas Cretaceous sections as given by Böse and Cavins is as follows.[4]

Maestrichtian	Escondido
Campanian	Navarro
Santonian	Taylor and upper and middle Austin
Coniacian	Lower Austin
Turonian	Upper Eagle Ford
Cenomanian	Lower Eagle Ford, Buda, Del Rio, and upper Georgetown
Albian	Lower Georgetown, Edwards, Comanche Peak, Walnut, and Glen Rose
Aptian	Travis Peak and basal sands

[1]F. M. Getzendaner, "Geologic Section of Rio Grande Embayment, Texas, and Implied History," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930), p. 1425.

[2]*Univ. Texas Bull. 66* (1916), p. 44, and *Bull. 2744* (1927), p. 144.

[3]D. M. Collingwood and R. E. Rettger, "The Lytton Springs Oil Field, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), pp. 953-75.

[4]Emil Böse and O. A. Cavins, "The Cretaceous and Tertiary of Southern Texas and Northern Mexico," *Univ. Texas Bull. 2748* (1927), p. 13.

	Uvalde Region		Austin Region	
	Formation	*Thickness (Feet)*	*Formation*	*Thickness (Feet)*
Eocene	Wilcox	350- 750	Wilcox	1,000-2,000
	Midway	250	Midway	300- 400
Upper Cretaceous	Escondido	500	Navarro	400- 600
	Anacacho	300- 500	Taylor	600-1,000
	Austin	350- 500	Austin	300- 400
	Eagle Ford	75- 400	Eagle Ford	30- 70
Lower Cretaceous	Buda	75- 150	Buda	30- 60
	Del Rio	75- 150	Del Rio	60- 90
	Georgetown	30±	Georgetown	70- 100
	Edwards	500±	Edwards	300- 350
	Comanche Peak	60±	Comanche Peak	40- 50
			Walnut	15
	Glen Rose	1,000-3,500	Glen Rose	1,000-2,000
	Travis Peak	100- 350	Travis Peak	100- 350

The igneous rock belt parallels and in part coincides with the Balcones zone of faulting and Lonsdale has suggested a possible actual relationship.[1] It can be shown that several of the igneous rock masses are immediately associated with the faults of this zone.

In the course of drilling during the past several years it has been shown that underlying the Cretaceous in this part of the state are Paleozoic rocks similar in character to those found in the Ouachita Mountains of Oklahoma and in the Marathon and Solitario regions of Texas.[2] These Paleozoic rocks, where exposed at the surface, are intensely folded and faulted. From the character of the rock it seems probable that similar folding and faulting characterize these formations underground. The belt of igneous rock coincides with the folded Paleozoic rocks underlying the Cretaceous. The Balcones fault zone likewise lies within this belt. This has led to the suggestion by the writer that both the Balcones fault zone and the igneous rocks may have a causal relationship with the underlying faulted Paleozoic rocks.[3] The approximate position of this

[1] J. T. Lonsdale, *op. cit.*, p. 24.

[2] Johan A. Udden refers to the Balcones fault zone and to the underlying igneous and metamorphic rocks as "an axis of an ancient series of rocks . . . a line of disturbance which certainly must be very old." *Amer. Inst. Min. Eng.*, Vol. 57 (1918), p. 1086.

[3] E. H. Sellards, "Rocks Underlying Cretaceous in Balcones Fault Zone of Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 819-28; H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *ibid.*, pp. 801-18.

Paleozoic belt in this part of the state and its relationship to the main Balcones fault and the igneous rocks is shown in Figure 1.

DESCRIPTION OF OIL FIELDS

THRALL OIL FIELD

The Thrall oil field is about 1 mile southeast of Thrall, Williamson County, in the belt of black soils derived from Cretaceous formations. The basal part of the Navarro formation is at the surface in this field underlain by the usual Cretaceous section of this part of the state (see Chapman field). The Austin chalk is reached at depths ranging from 1,000 to 1,200 feet and the basal Cretaceous Trinity sands at 3,290 feet (Magnolia Petroleum Company's Stiles No. 1). These formations dip eastward 60-100 feet to the mile. The oil is obtained from a serpentine mass at depths ranging from 612 to 950 feet. The total production to the end of 1931 was 2,206,207 barrels. The total producing area is approximately 472 acres.[1] The production to the acre to the end of 1931 was 4,650 barrels. The field was discovered when wells were being drilled for water in 1915 and is still producing about 30 barrels a day (April, 1932).

The serpentine mass of this field as mapped by Udden and Bybee is somewhat irregular in outline, approximately 4,800 feet in extent east-west and 5,000 feet north-south.[2] It is steepest at the south side, where the serpentine drops 275 feet or more (from −175 to −450 feet, sea-level datum) in ¼ mile. The slope from the somewhat flat-topped crest of the serpentine is steep near the field and very gradual farther away, particularly at the north.

The serpentine lies within the Taylor marl. Many well logs show 200-300 feet of Taylor marl under the serpentine. However, in a well assumed to be near the vent through which the serpentine came, only 10 feet of Taylor marl intervenes between the serpentine and the Austin formation. In this well the serpentine had a thickness of 547 feet, this being the maximum thickness of serpentine recorded in the field, because it thins toward the margins of the field. The pore space in the serpentine determined from seven samples was found by Udden and Bybee to vary from 21.9 to 35.6 per cent.

[1]The acreage given for this and the other fields referred to in this paper embraces the area within a boundary line including the outermost wells that afforded production. The area has been calculated by perimeter measurement by E. C. Sargent. Acreage measurements are only approximate and in some respects are misleading.

[2]Johan A. Udden and H. P. Bybee, "The Thrall Oil Field." *Univ. Texas Bull. 66* (1916). Also H. P. Bybee, "Some Recent Notes on the Thrall Oil Field of Williamson County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 6 (November-December, 1921), pp. 657-60.

The oil of this field has a gravity, as determined soon after the field was discovered, ranging from 39.8° to 40.9° Bé.[1] Ozokerite, commonly referred to as paraffine, separates from the oil in the wells and flow pipes and in some wells results in clogging the pipes. It is removed by pulling the rods and, if necessary, by steaming or by putting gasoline into the well.[2] Initial production of wells varied from 1 to possibly 5,000 barrels per day. Large and small wells occurred irregularly throughout the field. The wells make little gas or water. Not all of the serpentine was productive. No faulting has been recognized.

Available well records indicate apparent irregularities in the upper surface of the Austin chalk, but do not afford decisive evidence of doming. Immediately overlying the serpentine is a thin stratum referred to by the driller as "cap rock." In the northeast half of the field this rock consists very largely of a porous shell breccia. Toward the southwest the "cap" consists of clay or marls with some compact limestone. This rock, in the opinion of Udden and Bybee, indicates that the serpentine was extruded into the Taylor sea; subsequently the shell breccia formed on the flank which was more directly exposed to wave action, and marl and limestone on the side less exposed.

The interpretation of extrusive origin of the serpentine is further supported, in the opinion of Udden and Bybee, by (1) the shape of the igneous mass, which is reduced to a thin edge peripherally, (2) the minute structure of some samples of the rock, suggesting derivation from lava, and (3) the fact that beds of the Taylor marl near the surface are but slightly if at all arched or domed over the serpentine. Had a serpentine mass several hundred feet thick been intruded into the Taylor marl it would have produced doming in the overlying strata. A map of this field contoured on the serpentine, showing initial production of wells, is published in University of Texas Bulletins 66 and 2744.

CHAPMAN OIL FIELD

The Chapman oil field is located 14 miles southeast of Taylor, Williamson County, and 8 miles south-southeast of the Thrall field. The oil is obtained from a serpentine mass at a depth ranging from 1,500 to 1,900 or more feet from the surface. The field was discovered in January,

[1]E. P. Schoch and W. T. Reed, "The Chemical Composition of the Petroleum Obtained at Thrall, Texas," *Univ. Texas Bull. 66* (1916).

[2]Although commonly referred to as paraffine, Schoch has shown that this substance is ozokerite. *Ibid.*, pp. 79-81.

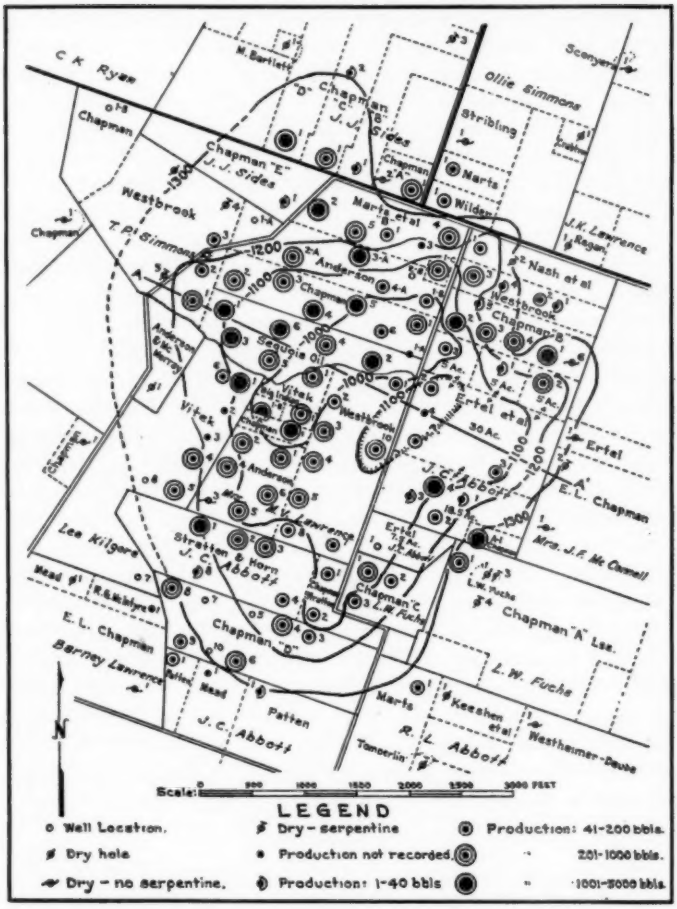

FIG. 2.—Contour map of Chapman oil field on upper surface of serpentine. Contour interval, 100 feet. The record on Ertel *et al.* J. C. Abbott No. 1, 30-acre lease, is not satisfactory and contouring for this well is in doubt.

1930, and to the end of 1931 had produced 2,945,088 barrels. The total producing area is 476 acres and the acre production to the end of 1931 was 6,180 barrels. The discovery of the field followed earlier test wells

in this region in which showings of oil had been obtained. The gravity of the oil is 36°-37° Bé. Little or no water occurs with the oil. Ozokerite or paraffine clogs the wells and flow pipes as in the Thrall field. The accumulation of paraffine is much more rapid in some wells than in others.

It is difficult to determine from well records the limits of the several formations in this field from the Wilcox at the surface to the Austin chalk which underlies the serpentine. The Midway-Wilcox contact is believed to be 1 mile northwest of the field. If so, the sandy shale in the discovery well, Abbott 1, at a depth of 325 feet, is probably upper Midway; otherwise it may be at the base of the Wilcox. Greensand reached in this

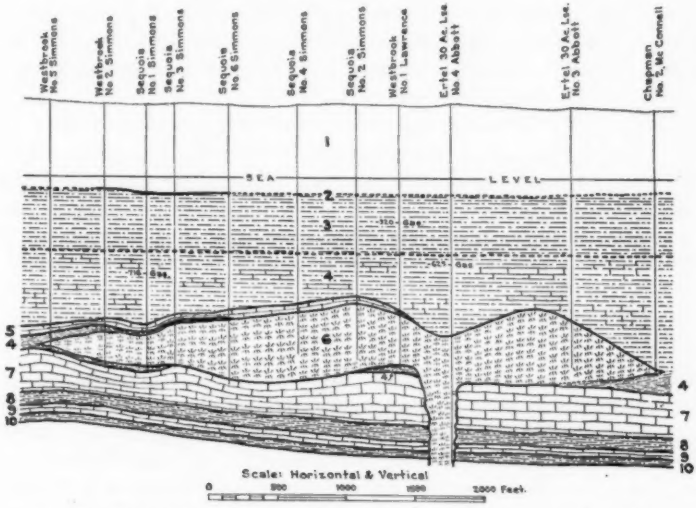

FIG. 3.—West-east cross section of Chapman oil field showing relation of serpentine mass to overlying and underlying formations. 1. Tertiary formations, Wilcox, and Midway; 2. Greensand horizon, probably at base of Midway formation; 3. Navarro; 4. Taylor; 5. Chalk stratum near base of Taylor marl; 6. Serpentine; 7. Austin; 8. Eagle Ford; 9. Buda; 10. Del Rio.

well from 600 to 613 feet (73 to 86 feet below sea-level) is probably the greensand which lies at or near the base of the Midway. This greensand gives a showing of oil in other wells and is probably the sand from which a small quantity of oil was obtained in several wells on the Bahn farm in Bastrop County.[1] A sand or sandy shale containing a showing of oil

[1]E. H. Sellards, *Mineral Resources of Texas, Bastrop County* (*Bur. Econ. Geol. Univ. Texas* (1929), p. 29.

reported in the discovery well at a depth of 1,155-1,164 feet is probably in the upper part of the Taylor marl. The same sand is reported in other wells and generally contains a showing of oil or gas. The Austin chalk is reached in this part of the field at a depth of approximately 2,125 feet, indicating a total thickness for the Navarro and Taylor formations and the serpentine of about 1,510 feet. A well located on the R. L. Abbott farm near the southeast margin of the field, entering the Austin at about 2,180 feet, appears to have reached the Edwards at 3,015 feet. This interval of 835 feet can not satisfactorily be divided into formations in this log. In the Bremond well in Milam County, a few miles northeast, however, the formation thicknesses within this interval are, in feet: Austin, 342; Eagle Ford, 71; Buda, 63; Del Rio, 46; Georgetown, 167; total, 689 feet. In the S. W. Jones well a few miles southwest of the field, the thicknesses are: Austin, 325; Eagle Ford, 148; Buda, 59; Del Rio, 52; Georgetown, 170; total, 754 feet.

The serpentine mass of this field, as shown by the accompanying contour map (Fig. 2), is approximately circular or with a slight north-south elongation, being about 4,000 feet wide and 5,500 feet long. The maximum difference in elevation from the crest to the margins of the serpentine is about 400 feet. The steepest slope on the serpentine is toward the northeast. Faulting is not definitely recognized in this field. Only a little water has been found. The initial production of oil varies from a few barrels to more than 5,000 barrels. Large and small wells are irregularly distributed. It is difficult to determine from the logs where productive strata are located in the wells, but they are apparently at varying depths in the serpentine. Wells drilled through the serpentine indicate that its thickness varies from 525 feet in the center to a few inches at the margins. Well No. 4 on the J. C. Abbott farm, the Ertel 30-acre lease, however, drilled 954 feet of serpentine from 1,666 to 2,260 feet. This well probably indicates the location of a vent through which the igneous rock came.

The serpentine lies within but close to the base of the Taylor marl. Most of the wells drilled through the serpentine in the central part of the field enter chalk with no intervening shale, but in wells near the margin, the drillers usually log gumbo and shale between the serpentine and chalk. In the absence of cores it is difficult to check these logs, since, as is well known, the soft serpentine drills like gumbo and shale. However, a sample was obtained from Westbrook's M. D. Lawrence No. 8 directly under the serpentine, depth 1,740 to 1,760 feet, which consists of fossiliferous brown shale probably of Taylor age. The records thus

indicate that though the serpentine rests on Austin chalk in the central part of the field, in some places, particularly near the margins, part of the Taylor marl intervenes between the serpentine and the Austin chalk. The serpentine is, therefore, a flattened ovate mass lying chiefly within the Taylor marl, but with a part of the base resting on the Austin chalk. An east-west section through the serpentine mass of this field is shown in Figure 3. On the small scale used in this illustration, it has not been practicable to indicate the relatively thin amount of Taylor that intervenes in places between the Austin chalk and serpentine.

Not all of the oil of this field is produced from the serpentine. A thin stratum of the limestone, probably similar to that at the west side of the Thrall oil field, overlies the serpentine and several of the wells are productive from this horizon. A contour map at this horizon indicates superposed doming in this limestone, probably somewhat less in amount than the relief on the top of the serpentine.

In the preliminary notice published about this field,[1] the writer expressed the view that doming above the serpentine is indicated in the sand stratum containing showings of oil and gas lying near the base of the Navarro or in the upper part of the Taylor marl. Later drilling indicates two or more such horizons yielding showings of oil and gas. With these more complete records, it is doubtful if doming exists above the chalk which overlies the serpentine in this field.

The Austin chalk underlying the producing zone is highest at the west side of the field and lowest on the southeast, indicating the normal southeast dip of this region. Some irregularities occur, but the records are too few as yet to determine whether these irregularities are actual or are due to imperfect logging of the wells.

If the serpentine of this field is of extrusive origin, as seems probable, the lava flow came in early Taylor time and was probably subaqueous, as indicated by the relative flatness of the serpentine mass. The apparent doming of the chalk stratum overlying the serpentine may be incidental to the presence of the serpentine mass at the time the chalk was being formed.

YOAST FIELD

The Yoast (Cedar Creek) field (Fig. 4) is about 4 miles southwest of Cedar Creek post office, in the southwestern part of Bastrop County. The oil is obtained from serpentine at depths ranging from 1,335 to 1,500 feet below the surface. The field was discovered in November, 1928,

[1] E. H. Sellards, *Mineral Resources of Texas*, *op. cit.*

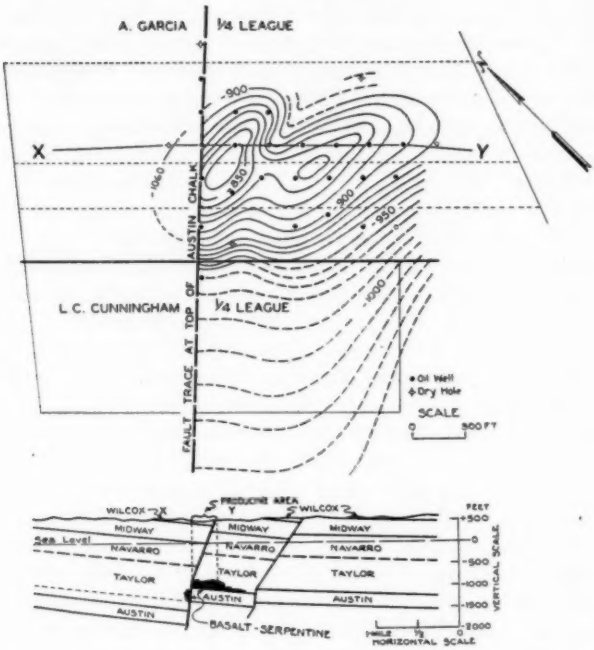

FIG. 4.—Structure contour map and cross section of Yoast oil field, Bastrop County, Texas. Production comes from serpentine in Taylor marl. Structure contour interval, 10 feet, datum sea-level. Note difference in horizontal scales of map and section. Cross section extends far beyond edges of field and eastern fault is beyond edge of map. (After D. M. Collingwood, "Magnetics and Geology of Yoast Field, Bastrop County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (September, 1930), Fig. 1 and Fig. 3).

having been located as a result of drilling to test a fault exposed at the surface. Total production to the end of 1931 was 695,777 barrels. The producing area includes about 64 acres and the acre production to the end of 1931 was 10,860 barrels. The oil is dark in color and has a gravity of about 27° Bé. Slightly salty water is produced with the oil by most of the wells in the field. More than 60 per cent of the fluid produced from some wells is water. Initial production varied from a few to about 2,000 barrels. Relatively little paraffine accumulates in the wells and cleaning of wells is seldom necessary.

The surface formations in this field are the Wilcox and Midway. A fault trending northeast-southwest passes through the field, the Midway being exposed on the southeast, upthrown side, and the Wilcox on the downthrown side. The thicknesses of the underlying Cretaceous formations to the Edwards, as indicated by a well on the Trigg farm about 2 miles south of the field, are as follows, in feet: Navarro-Taylor (estimated), 1,300; Austin, 288; Eagle Ford, 37; Buda, 65; and Georgetown, 70. These formations dip southeast 150-200 feet per mile.

The serpentine mass in this field is approximately circular in outline and the top is flattened. The difference in elevation between the crest and margins of the serpentine is 230 feet or more. As previously mentioned, a small fault cuts the serpentine. The production is chiefly, if not entirely, on the upthrown side of the fault. This fault is part of an extensive fault series that is known to extend from Guadalupe River in Caldwell County through Bastrop County.

The serpentine of this field is near the base of the Taylor marl. A well drilled on the downthrown side of the fault, Cranfill and Reynolds' Yoast No. 6, records the chalk at 2,066 feet, with 251 feet of gumbo, shale, and lime shells intervening between the serpentine and the chalk. The serpentine in this well, with some intermixture of shale, is 240 feet thick. On the upthrown side of the fault in the eastern part of the field, the Austin chalk is reached directly under the serpentine in The Texas Company's Yoast No. 7 at 1,909 feet.[1]

Faulting in this field has been studied by Collingwood,[2] who finds evidence of two periods of movement. The first occurred following Austin time and the fault displacement amounted possibly to about 200 feet. The second occurred much later, in post-Wilcox time, and the total throw on this fault in the Austin is about 500 feet, whereas in the Wilcox it is only approximately 300 feet. The serpentine was extruded into the Taylor sea subsequent to the first faulting and is affected by the late faulting only.

[1]Near the west line of Bastrop County, south of Colorado River, and 450 feet north of the Austin-Bastrop highway in the José Antonio Navarro grant, the Humble Oil and Refining Company drilled a well in 1931 in which was encountered Austin chalk (?) from 1,275 to 1,303 feet, serpentine from 1,303 to 1,411 feet with a showing of oil at 1,345 feet, and Austin chalk from 1,411 to 1,493 feet, the total depth. This serpentine mass was located by magnetometer survey.

[2]D. M. Collingwood, "Magnetics and Geology of Yoast Field, Bastrop County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (September, 1930), pp. 1191-97.

Contour maps of this field on the serpentine have been published by Collingwood[1] and by Woolsey and Mackay.[2]

LYTTON SPRINGS OIL FIELD

The Lytton Springs oil field (Fig. 5) is located 2 miles southeast of Lytton Springs in Caldwell County. The surface formation is Midway.

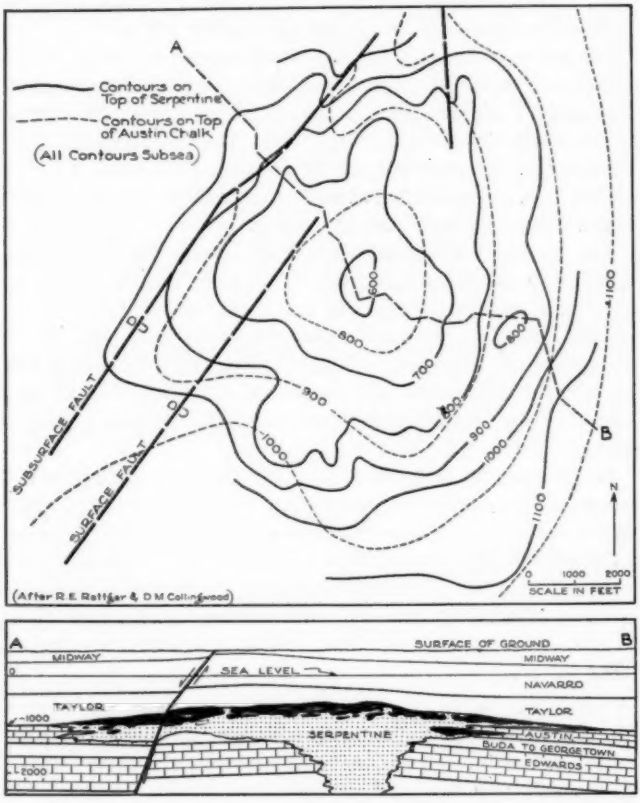

FIG. 5.—Structure contour map and cross section of Lytton Springs oil field modified by F. H. Lahee from Rettger and Collingwood. Reproduced from Lahee, *Bull. Geol. Soc. Amer.*, Vol. 43, 1932.

[1]D. M. Collingwood, *op. cit.*, p. 1194 (reproduced in Figure 4).

[2]*Mineral Resources of Texas, Bastrop County* (Bur. Econ. Geol., Univ. Texas, 1930). Contour map by Vernon Woolsey and Donald K. Mackay.

The regional dip of these formations ranges from 100 to 200 feet per mile southeast, but in the Lytton Springs area it is interrupted by faulting and doming. The oil occurs in a serpentine mass at depths ranging from 1,120 to about 1,400 feet.

The field was discovered in 1925 and is still producing (1932). Large and small wells are close together, depending on porosity of the serpentine. Some wells flowed 5,000 barrels a day for a few days. The total production to the end of 1931 was 6,377,000 barrels. The total producing area is about 1,385 acres and the acre production to the end of 1931 was 4,600 barrels. The oil has a gravity of about 38° Bé. The wells produce only small amounts of water, probably less than 10 per cent. Wells are troubled with paraffine.

The serpentine mass of this field is oval with slight north-south elongation. Its dimensions approximate 9,500 by 9,000 feet. The cone of serpentine is flat-topped with steep sides. From the crest the slope, aside from minor irregularities, is gradual in all directions for distances ranging from 2,500 to 4,000 feet, beyond which it is abrupt. The difference in elevation from a high point on the crest to the lowest point that can be measured on the margin is 500 or 600 feet.

The serpentine lies near the base of the Taylor marl. It rests directly on the Austin chalk in part of the field and, in places, takes the place of the chalk. However, Bybee and Short have shown that in a well near the margin of the field, part of the Taylor marl underlies the serpentine.[1] The known thickness of the serpentine ranges from more than 500 feet in the central part of the field to a few feet or almost nothing at the margins.

A slight structural dome at the surface overlies the serpentine. At the crest of the dome, according to Collingwood and Rettger (Fig. 4), lower Midway is exposed surrounded by middle and upper Midway.[2] The structure was found from surface exposures by John Blanchard and was drilled on his recommendation.

Considerable faulting occurs near the serpentine dome. One fault, seen at the surface south of the field, trends northeast directly toward the serpentine mass and possibly continues into the field.[3] Two or three

[1]H. P. Bybee and R. T. Short, "The Lytton Springs Oil Field," *Univ. Texas Bull. 2539* (1925), p. 12.

[2]D. M. Collingwood and R. E. Rettger, "The Lytton Springs Oil Field, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), p. 956. See also E. W. Brucks, "Geology of the San Marcos Quadrangle," *idem*, Vol. 11, No. 8 (August, 1927), pp. 835-48.

[3]Collingwood and Rettger, *op. cit.*, p. 956.

other faults are recognized near the field. Collingwood and Rettger recognize two periods of faulting, the first being probably in mid-Austin time, and the second a post-Wilcox movement along the same fault plane.

The upper surface of the chalk presents extreme irregularity. Bybee and Short note relief of 610 feet on the upper surface of the chalk.[1] Collingwood and Rettger find the Austin formation to have been folded, the doming in this formation corresponding with the surface dome.[2]

Bybee and Short believe the serpentine to have been largely extrusive, the lava being erupted into the lower Taylor sea. At the same time, in their opinion, sills were forced into the underlying Austin chalk. Collingwood and Rettger regard the serpentine as in part altered extrusive lava and ash and in part altered sill and dike rock.

A contour map on the serpentine of this field and a full discussion of the geologic conditions including initial production of wells will be found in the publications cited.

DALE OIL FIELD

The Dale oil field[3] is 3 miles east of Dale in Caldwell County. The oil is obtained from a serpentine mass at depths ranging from 1,915 to 2,250 feet. The field was discovered in August, 1927, and to the end of 1931 had produced 742,077 barrels of oil. The total producing area is approximately 235 acres; the acre production to the end of 1931 was 3,160 barrels. The gravity of the oil is about 38° Bé. Previous to the discovery of oil, serpentine had been found in several wells drilled in this general locality. The Smilock Oil Company's Clingensmith No. 1 north of the discovery well logged 220 feet of unproductive serpentine; the Reiter-Foster Oil Corporation's Brown No. 1, more than 2 miles south, and near the Buchanan field, had 96 feet of serpentine from which a barrel or more of oil was bailed; and the Murchison-Fain's Myers No. 1, about 1 mile west of a line between these wells, had 8 feet of impervious serpentine.

The discovery well in the field was The Texas Company's Beatty No. 1 A, in which was found serpentine from 2,121 to 2,271 feet, underlain by Austin chalk. A showing of oil and some salt water was obtained in the serpentine and, after the well was swabbed, commercial production was obtained. Production in this field has been notably irregular, many non-producing wells having been drilled into impervious serpentine.

[1]Bybee and Short, *op. cit.*, p. 13.

[2]Collingwood and Rettger, *op. cit.*, p. 658.

[3]The surface geology is described by E. W. Brucks, *op. cit.*, p. 838.

Initial production ranges from a few to more than 800 barrels. Paraffine accumulates in the wells.

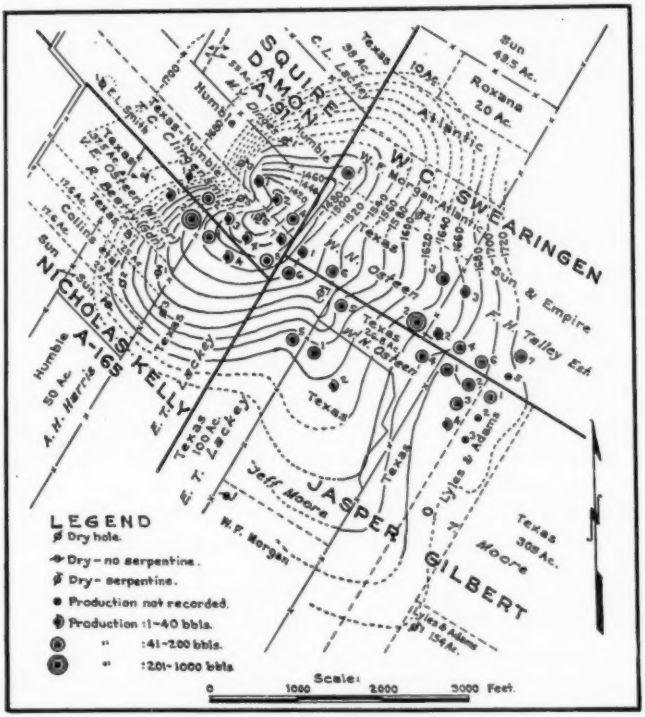

FIG. 6.—Contour map of Dale oil field on upper surface of serpentine, by J. M. Hancock. Contour interval, 20 feet. (Steep dip bounding field on west is probably a fault.—Editor.)

The surface formation in this field is the Wilcox. Two wells within the field have been drilled to the Edwards formation. In the absence of samples it is difficult to determine the thickness of the Midway and uppermost Cretaceous formations, the Navarro and Taylor. A log of The Texas Company's Beatty No. 1 B gives the top of the Austin chalk at 2,143 feet; of the Edwards limestone at 2,661 feet. In the Humble Oil and Refining Company's Clingensmith No. 3 the Austin was entered,

according to the log, at 2,282 feet and a core of Edwards limestone was obtained at 2,633 feet. The thickness of the intervening formations, Austin, Eagle Ford, Buda, Del Rio, and Georgetown, can not be determined satisfactorily from these logs.

The upper surface of the serpentine mass in this field, as shown by the accompanying map prepared by J. M. Hancock (Fig. 6), has an irregular, steep, northwest slope and a much more gradual southeast slope. Its diameter is about 5,000 feet. The difference in elevation from the crest to the lowest point reached by wells is about 450 feet.

Stratigraphically the serpentine of this field lies at the base of the Taylor and rests directly on the Austin chalk, whose upper surface, as shown by these records, is very irregular. The maximum production is from mixed serpentine and chalky material at the top of the serpentine mass. Faulting in this field has not definitely been established, although faulting probably affected the Austin and older formations.

BUCHANAN OIL FIELD

The Buchanan (Brown-Cude) field (Fig. 7) is about 3 miles southeast of the town of Dale in Caldwell County. Oil is obtained from serpentine at depths ranging from 1,711 to 2,075 feet. The field was discovered in August, 1929, by means of a well located to test a surface fault. The total production to the end of 1931 was 93, 716 barrels. The producing area in this field includes about 64 acres; the acre production to the end of 1931 was 1,460 barrels. The density of the oil is 38.5°-39° Bé. gravity. Initial production is irregularly distributed, the maximum having been about 1,000 barrels. Little water is found.

Oil production is reported to come largely from the upper 20 feet of the serpentine, which is probably the most porous part. Although showings of oil are found through the full thickness, deepening the wells in the serpentine below this upper zone is said to have resulted in no appreciable increased production. The initial production of wells in this field varies; the maximum is 1,000 barrels. Dry wells are found offsetting producers. In addition to production from the serpentine, there is some production in at least one well, The Texas Company's Cude No. 1, from limestone rock above the serpentine.

Wilcox sandstone crops out in this field. The section in some wells is shortened as the result of cutting the normal fault which passes through the field. Buchanan's Cude A 2, which starts on the downthrown side of the fault, appears to have cut the fault within the Austin, only 41 feet of this chalk having been encountered. Production of about 15 barrels of oil per day was found in the Edwards limestone at 2,424 feet.

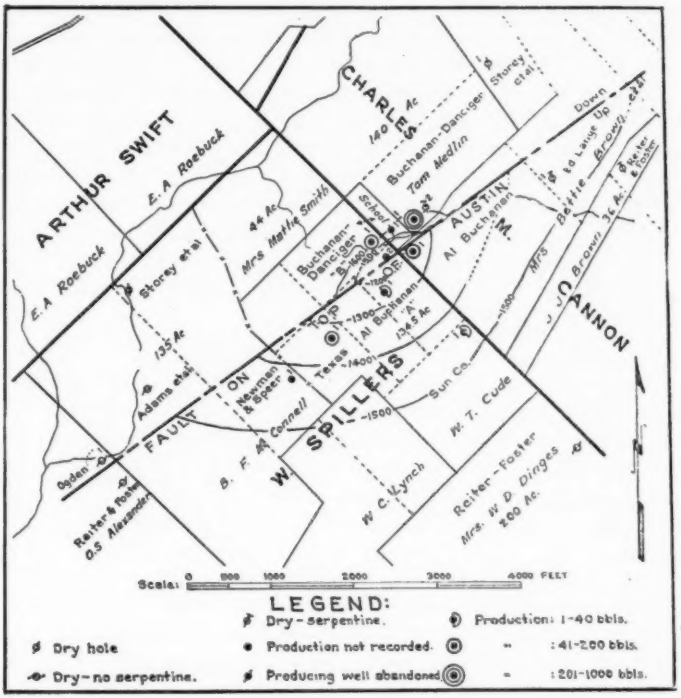

FIG. 7.—Contour map of Buchanan oil field on upper surface of serpentine. Contour interval, 100 feet.

A well drilled by Reiter-Foster on the J. J. Brown farm near this field and on the upthrown side of the fault entered Austin underlying serpentine at 2,043 feet, and Edwards at 2,483 feet. In this well the Wilcox and Midway appear from the log and samples to extend to nearly 1,000 feet, and the succeeding 1,043 feet is assigned to the Navarro and Taylor. The interval from the top of the Austin to the top of the Edwards appears from the log, supported by samples, to have been approximately as follows: Austin-Eagle Ford, 272 feet; Buda, 51 feet; Del Rio, 51 feet; Georgetown, 71 feet.

The serpentine mass is elongated northeast-southwest and is cut by a fault which trends northeast. The throw of the fault is not fully determined and may not be large in the serpentine, although it is known

to be several hundred feet in the chalk. Production is obtained on both sides of the fault, the largest initial production having been from a well on the downthrown side. The difference in elevation from the crest of the serpentine mass on the upthrown side to the lowest point recorded by the wells drilled on that side is about 235 feet. The serpentine mass on the downthrown side has about 200 feet of relief. Of four wells drilled through the serpentine, three log Austin chalk immediately under the serpentine, while the fourth, Buchanan No. 2 Medlin, at the northern edge of the field, logs 18 feet of shale above the chalk. The maximum recorded thickness of the serpentine is 412 feet near the center of the field. The few other wells drilled through the serpentine show a thickness ranging from 68 to 205 feet.

LYTTON SPRINGS TOWNSITE FIELD

Two small producing areas have been found west of Lytton Springs field, one in the townsite, one west of the townsite. The former is on the southeast side and the latter on the northwest and downthrown side of a fault parallel with the Lytton Springs field fault. The serpentine is above the Austin chalk and is found only on the southeast side of the fault at the townsite and only on the southwest side west of the townsite. The total production for both areas has been about 6,000 barrels from 3 wells, one in the townsite, two in the other pool.

Serpentine has been penetrated in several wells in and adjacent to the Lytton Springs townsite. A well drilled by Cranfill and Reynolds,' Cardwell No. 1, obtained production amounting to about 25 barrels initial. This well is logged as having found "cap rock" from 1,504 to 1,509 feet and serpentine from 1,509 to 1,534 feet. The Austin is logged as directly underlying the serpentine. This well, drilled in October, 1928, is still producing a few barrels per day. All offset wells were dry.

Several wells have been drilled by Batts and Harper on the Tabor and Miller farms, about ¾ mile west of Lytton Springs townsite. In Miller No. 1, serpentine was reached at 1,640 feet and the well was drilled to 1,778 feet. In Tabor No. 1, chalk underlying 128 feet of serpentine was reached at 1,908 feet. Initial production was 5 or 10 barrels and the well is still flowing. In Tabor No. 2, serpentine was entered from 1,815 to 1,845 feet, in No. 3 from 1,780 to 1,819 feet, but No. 4 found no serpentine. Small production has been obtained from Cranfill and Reynolds' Strawn No. 2. The serpentine at this locality represents in part re-worked material, as some of the cores contain fossils.

SCHIMMEL-BATTS FIELD

Several wells have been drilled into serpentine on the Williams and Ferguson ranches in Bastrop County about 2½ miles southwest of the

Yoast field and between this field and Lytton Springs. The discovery well drilled by the Texas Petroleum Company (Schimmel and Batts) on the J. C. Williams ranch, and completed May 15, 1931, is opened intermittently, flowing 10-12 barrels per day. Another well completed in June, 1931, on the Ferguson ranch seems likely to afford a small production. This second well is reported to have been drilled 200 feet into serpentine. A third well, Trigg No. 3, was completed by the same operators in August, 1931. The top of the serpentine is reported at 1,357 feet and the total depth at 1,418 feet. It had the largest initial production of the three, making 11 barrels per hour, but will produce only a few barrels a day.

Johnson-Batts' Trigg No. 1, north of these wells, entered chalk at about 1,600 feet after being drilled through 79 feet or more of serpentine. The Edwards limestone, with some serpentine, according to the log, was reached at 2,060 feet. Another well drilled on the Trigg ranch disclosed 344 feet of serpentine underlain by Austin chalk. A well drilled on the J. P. Williams ranch entered Austin chalk at 1,610 feet underlying 41 feet of serpentine. The serpentine at this locality, so far as determined, rests on the Austin formation. The field was discovered because of a magnetic "high." The total production of about 1,500 barrels has been used for fuel oil.

DESCRIPTION OF OTHER OCCURRENCES

KIMBRO AREA

Showings of oil in serpentine have been found at Kimbro in the eastern part of Travis County, 18 miles east of Austin and 22 miles north of the basaltic intrusion, Pilot Knob.[1] Fourteen wells have been drilled at this locality within an area of a square mile or two. Two were drilled on the Smith estate at Kimbro by the Taylor Refining Company; the one located at the west side of the road entered serpentine at 658 feet; water was found in this well, with a little oil, and it was abandoned at 701 feet; the other, at the east side of the road, entered serpentine at 678 feet; oil was found underlain by salt water in the top of the serpentine, and showings of oil at greater depth, and the well was abandoned at 900 feet.

Sun Oil Company's Nagle No. 1, one mile south of Kimbro, entered serpentine at 658 feet. The serpentine was porous and, although it

[1] R. T. Hill and T. W. Vaughan, "Austin Folio," *U. S. Geol. Survey Folio 76* (1900).

yielded showings of oil, it produced a large flow of salt water. A second well on this farm located 100 feet northeast of the first drilled in serpentine from 636 feet to more than 988 feet, and also gave a flow of water. Several wells drilled at and near this locality record impervious serpentine underlain by Austin chalk.

The serpentine at the Kimbro locality is unusual in the quantity of water it contains, as shown by wells on the Smith and Nagle farms. The serpentine rests, so far as determined, on the Austin formation. The occurrence of serpentine at this locality is described by Lonsdale.[1]

DARST CREEK FIELD

Serpentine was found in several wells in the northeastern part of the Darst Creek oil field in Guadalupe County. The production in this field is from the Edwards limestone and is obtained from wells located on the upthrown side of a fault. The serpentine mass, which is of limited extent, occurs adjacent to the fault. Gulf Production Company's Malaer No. 1 drilled serpentine with more or less chalk from 2,081 to 2,295 feet. A showing of oil is reported in this well from serpentine at 2,223 feet. Serpentine is reported from the two other wells drilled on this lease, Nos. 2 and 3, and from a few other wells in this part of the field. This occurrence of serpentine has been described by H. D. McCallum.[2]

UVALDE REGION

Unaltered and serpentinized basaltic masses and sedimentary serpentine occur extensively in the Uvalde region.[3] Lonsdale[4] has described many of the localities, and Getzendaner[5] has shown that sedimentary serpentine, derived from the erosion of basaltic rocks, occurs in this part of the state in large amounts in the Upper Cretaceous formations from the Eagle Ford to the Escondido.

[1]Lonsdale, *op. cit.*, p. 123; also, E. H. Sellards, *Mineral Resources of Texas, Travis County* (Bur. Econ. Geol., 1930).

[2]Paper read at the San Antonio meeting of The American Association of Petroleum Geologists, March, 1931. Manuscript, "Darst Creek Oil Field."

[3]T. W. Vaughan, "Uvalde Folio," *U. S. Geol. Survey Folio 64* (1900); petrography by Whitman Cross; R. T. Hill and T. W. Vaughan, "Geology of the Edwards Plateau," *U. S. Geol. Survey 18th Ann. Rept.*, Pt. 2 (1898), p. 256.

[4]J. T. Lonsdale, *op. cit.*, pp. 15-23; 124-28.

[5]F. M. Getzendaner, *op. cit.*, pp. 1428-29; *Mineral Resources of Texas, Uvalde County* (Bur. Econ. Geol., 1931).

In Zavala County[1] a serpentine core from I. T. Pryor's Fee No. 2, on the south side of the Emily W. King survey, about 15 miles south of Uvalde, depth 1,447-1,449 feet, was identified by W. H. Tomlinson as containing "altered nepheline basalt, with primary augite, nepheline, olivine, and magnetite; with secondary calcite, bowlingite geolites, chlorite, serpentine, and pyrite;" with texture "thickly and coarsely porphyritic."[2] The cavities of this core are filled and adjacent areas impregnated and all fracture planes stained with asphalt. About 20-30 feet above the level of this core the rock is more completely altered and contains much oil-stained calcite. At 1,458 feet the rock is essentially unaltered and consists, according to Tomlinson, of nepheline basalt with no secondary minerals. This core has been preserved and a photograph of it supplied for this paper by Getzendaner (Fig. 8). In this well progressive alteration is seen from the very hard, essentially unaltered basalt at and below 1,458 feet to serpentine with oil-filled cavities at and above 1,449 feet. A similar gradation from serpentine to unaltered basalt is recorded by Lonsdale in surface exposures.

Chloritic and ashy material found under the Little Fry Pan surface structure in the southwestern part of Uvalde County seems to be extrusive. Thin limestones bedded in the chlorite and ash contain fossils. Practically all the Eagle Ford and Austin, and the Taylor section below the Anacacho are chloritic and ashy. Although there is considerable structural relief on the surface, it disappears below the Austin or Eagle Ford, the Lower Cretaceous showing little or no uplift. The surface structure in the Anacacho and Escondido is apparently due in some manner to the chlorite and ash deposit. Considerable asphalt or asphaltic oil was found in the Pure Oil Company's Smythe and Smith No. 1 on Little Fry Pan at several places between the surface and the base of the anhydrite section in the Lower Cretaceous.[3]

PRODUCTION

All the igneous rock from which oil production has been obtained in the several fields of the Gulf Coastal Plain of Texas is altered. The degree of alteration varies, but in general the oil-bearing rock is chlorite

[1]The county was named after Lorenzo de Zavala and at a recent session of the legislature, the spelling was fixed as Zavala.

[2]F. M. Getzendaner, *Mineral Resources of Texas, Zavala County* (Bur. Econ. Geol., 1931); also, personal communication.

[3]This paragraph was very kindly contributed by R. A. Liddle.

FIG. 8.—Core of nepheline basalt, altered to serpentine-like rock, from 1,447 to 1,449 feet in Pryor's Fee No. 2, Zavala County. Cavities in core filled with asphalt. At 1,458 feet in this well the rock is unaltered basalt. Photo by Getzendaner.

or serpentine derived from basalt or closely allied rock. The rock is believed to represent, in large part, extrusions cut by later intrusions in the form of dikes or sills and plugs. Sedimentary serpentine (hydrated ash and tuff) occurs extensively in these formations, but the igneous rock of the principal producing fields appears to have been altered in places and to contain water-transported serpentine only in its surface layers.

The total production to the end of 1931 from the six major commercial fields of this kind was 13,344,646 barrels. Production by fields to the end of May, 1931, is given in the accompanying table.

Drilling costs are low because of the shallow depths, 700 to 2,250 feet, and the soft formations, clays, marls, and sands, but production

PRODUCTION IN BARRELS BY YEARS—SOUTHWEST TEXAS SERPENTINE FIELDS (HUMBLE OIL AND REFINING COMPANY)

Year	*Thrall*	*Dale*	*Buchanan*	*Lytton Springs*	*Chapman*	*Yoast*	*Total Serpentine Fields*
1915	994,874						994,874
1916	461,518						461,518
1917	182,567						182,567
1918	136,378						136,378
1919	92,184						92,184
1920	58,883						58,883
1921	73,000						73,000
1922	51,000						51,000
1923	34,000						34,000
1924	25,000						25,000
1925	17,000			2,715,566			2,732,566
1926	17,000			1,828,150			1,845,150
1927	13,200	60,318		742,193			815,711
1928	12,903	306,373		484,217		5,272	808,765
1929	12,500	172,157	7,328	353,624		475,944	1,021,553
1930	12,200	109,963	56,347	292,784	1,775,593	151,512	2,398,309
1931	12,000	93,266	30,041	245,247	1,169,585	63,049	1,613,188
	2,206,207	742,077	93,716	6,661,781	2,945,088	695,777	13,344,646

AVERAGE DAILY PRODUCTION FOR DECEMBER, 1931
(National Oil Scouts Association of America Yearbook for 1932, Dallas, Texas, p. 117)

Field	*Number of Producing Wells*	*Daily Production for Field*
Thrall	12	49
Dale	36	229
Buchanan	4	69
Lytton Springs	199	612
Chapman	107	1,697
Yoast	16	185
Lytton Springs townsite	3	5
Schimmel-Batts	3	7
Total	380	2,853

is as a rule spotted, and the average capacity of wells is small and good wells are irregularly distributed. Due probably to high porosity in the rock around certain drill sites, most wells with large initial production decline rapidly and require pumping.

Owing to the ease of drilling, peak production has been reached in each of these six fields during the first year following discovery. The oil from the serpentine is high grade and has a paraffine base. The gravity ranges from 27° to 40° Bé. In most of the fields paraffine or ozokerite separates out of the oil to such an extent as to more or less

clog tubing and require removal. As a rule very little water is produced with the oil.

Not all of the production credited to some of the fields is from serpentine. In the eastern part of the Thrall field production is obtained in a shell breccia overlying the serpentine. Similarly, throughout much of the west side of this field is a limestone stratum immediately above the serpentine which yields oil. Both the shell breccia and the limestone were formed subsequent to the extrusion of the serpentine, and belong to the Taylor marl. A limestone bed yields oil throughout a considerable area at Chapman. Production is obtained from limestone in one well of the Buchanan field.

STRATIGRAPHIC POSITION OF SERPENTINE

In all of the commercially productive fields, the igneous rock lies at or near the base of the Taylor marl and in no producing field does the top of the serpentine extend above this formation. On the other hand, the serpentine may, and often does, extend below the base of the Taylor marl. This is to be expected, because vents through which the magma came are doubtless filled with igneous rock. Such a vent has apparently been penetrated in the Chapman field, where a well was drilled 954 feet into serpentine. The level reached by this well was probably that of the Buda or Del Rio formation. The igneous magma in forcing its way through these formations might well intrude the adjacent formations, forming sills, laccoliths, and dikes. Drilling records indicate frequent occurrence of serpentine, particularly in the Austin chalk from which some production has been obtained. A well at Lytton Springs, Harper's Cardwell No. 3, is reported to have produced 400 barrels daily from a 125-foot body of serpentine in the Austin chalk.[1]

In some of the fields serpentine partly replaces the Austin and Taylor formations because of contemporaneous extrusion or of engulfment of the partly consolidated sediments. Lateral buckling of the sediments by igneous rock might explain the irregularity of the present position of the Austin under some of the fields. The extrusion of lava appears to have taken place in early Taylor time and the Taylor sediments which were then accumulating presumably were but little compacted, so that the emerging lava may have easily widened the vent and formed low-angled volcanic cones.

In surface exposures in Kinney, Uvalde, Medina, and Travis counties, part of the serpentine may be seen to grade into unaltered ferro-

[1]Collingwood and Rettger, *op. cit.*, p. 967.

magnesian rock. This condition is not found in any of the producing fields where the rock is completely serpentinized. The maximum recorded thickness of this kind of rock is 954 feet in the Chapman field. On the other hand, in the Pryor's Fee well No. 2 in Zavala County the serpentinized rock at 1,447-1,449 feet grades into unaltered basaltic rock at 1,458 feet.

HISTORY OF DISCOVERIES

The region in the Gulf Coastal Plain in which serpentine may be expected to occur was outlined soon after the first field of this kind was discovered and the subsequent discoveries have been within this belt.[1] However, the discovery of productive serpentine masses by surface indications presents special difficulty, since the serpentine is buried beneath later formations. Some of the fields have been discovered under anticlinal structure mapped at the surface. Thus the Lytton Springs field was drilled because of the presence of a surface dome. Yoast and Buchanan fields were discovered when drilling to test faults. In all instances, however, the discovery of the serpentine has been while drilling with the chief expectancy of finding oil or water in sedimentary rocks.

FAULTING

Faults have been found in most serpentine fields. In the Thrall and Chapman fields, faulting has not been definitely recognized, whereas in some other fields, Yoast, Lytton Springs, Dale, and Buchanan, faulting is more or less well determined. It is a well established fact that faulting in some of these fields, notably Yoast, occurred in two periods, first at or near the close of Austin time and again in post-Wilcox time. It is possible that Thrall and Chapman may have been affected by pre-Taylor faulting, the faults being concealed by the later deposition; or minor undetected faulting may exist.

SOURCE OF OIL

Oil in the serpentine is derived from various sources. In several fields it is probably largely from the Taylor marl, because in all producing fields the upper surface of the serpentine is in contact with this formation. Also, in the largest producing fields, Thrall, Chapman, and Lytton Springs, Taylor marl underlies part of the serpentine. Also, as previously stated, a little production in Thrall and Chapman comes from the Taylor. This formation produces at Somerset, Atascosa County, and at Corsicana, Navarro County.

[1] Johan A. Udden, *op. cit.*, p. 63.

On the other hand, it does not necessarily follow that all of the oil, or that the oil in all of the fields, comes from the Taylor marl. The serpentine rests on the Austin chalk, which has produced some light oil. In fields affected by faulting, as Yoast, oil may have moved upward into the serpentine. In Buchanan, where serpentine adjacent to a fault rests on oil-bearing Edwards limestone, the probability of oil coming into the serpentine from that formation is very great.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 8 (AUGUST, 1932), PP. 769-776, 1 FIG.

OCCURRENCE OF OIL IN CRYSTALLINE ROCKS IN COLORADO[1]

F. M. VAN TUYL[2] and R. L. McLAREN[2]
Golden, Colorado

ABSTRACT

The occurrence of oil in crystalline rocks in Colorado includes (1) seepages of oil in pre-Cambrian gneiss near the town of Golden and (2) oil in amygdaloidal cavities of basalt dikes on both flanks of the Colorado Rocky Mountains in the southern part of the state. The conclusion is reached that the oil of the seepage in the gneiss is derived from sedimentary rocks presumably of Dakota age faulted under the pre-Cambrian crystalline rocks during the Laramide revolution. The oil of the amygdaloidal cavities of basalt is ascribed to the natural distillation of organic matter of kerogen-bearing shales penetrated by the intrusions.

INTRODUCTION

For many years, the existence of oil and gas in crystalline rocks in Colorado has been known and the tendency on the part of some geologists has been to refer the oil of these occurrences to an inorganic source. In the present paper, an effort is made to interpret the phenomena in the light of our present knowledge of the structure and geologic history of the Colorado Rocky Mountains and the modern conceptions of the origin of petroleum.

The most interesting relation of oil to crystalline rocks in Colorado is found near Gold Run Canyon (also called Golden Gate Creek) about 2 miles northwest of Golden, and 18 miles south of the Boulder oil field, where several small masses of gravel overlying gneiss in the bed of a ravine are cemented by bituminous matter. In southern Colorado oil occurs in small quantities in amygdaloidal cavities of basalt dikes both in Huerfano and Las Animas counties on the east side of the Colorado Rocky Mountains and in Archuleta County on the west flank of the mountains.

OIL SEEPAGE IN GNEISS NEAR GOLDEN

This seepage has been referred to by several earlier writers, but the first serious attempt to explain the occurrence on the basis of structural

[1]Read by title before the Association at the San Antonio meeting, March 21, 1931. Manuscript received, June 27, 1931.

[2]Colorado School of Mines.

geology seems to have been made by the senior writer[1] in 1924. In a later paper by Irwin,[2] essentially the same interpretation is given. Both of these accounts, however, are too brief to give a clear representation of the situation.

The seepage occurs along a small ravine tributary to Gold Run on the north, about ½ mile west of the pre-Cambrian-Fountain contact at the mouth of the canyon and about 300 feet north of the junction of the tributary with the main stream, in the NE. ¼, SW. ¼ of Sec. 20, T. 3 S., R. 70 W. At several points along the bed of the tributary for a distance of about 150 feet there are several small remnants of conglomerate with bituminous cementing material. At one point near the bituminous gravel an iridescent scum now appears on the surface of a small stagnant pool of water. Careful examination of this reveals that it is due to a film of iron oxide. However, films of live oil have been observed by the writers on the same pool on several occasions during the past five years. Professor R. A. Baxter, of the department of chemistry of the Colorado School of Mines, has examined some of the bituminous matter derived from the conglomerate. This was extracted with carbon tetrachloride. Upon evaporation, the residue was found to be a black, thick substance which was stringy when hot and brittle when cold.

When retorted, the bituminous gravel gave off dark oil with a greenish tinge and an odor of burnt coffee. The refractive index was found to be 1.476 and the specific gravity 0.895. The oil did not show traces of either sulphur or nitrogen.

TOPOGRAPHY OF AREA

Reference to the accompanying geological map and structural cross section of the area reveals the fact that the seepage is located near the eastern border of the Front Range of Colorado. The topography of the mountain belt is of the early mature type resulting from the dissection of the Rocky Mountain peneplain in late Tertiary and Quaternary time. Recent studies by the senior writer have revealed the fact that the physiographic history of the crystalline area is somewhat simpler than that of the Foothills area at the east, inasmuch as the crystalline area is generally considered to be in the early mature stage of the third cycle of erosion, while there is evidence that the Foothills area is in the youthful stage of

[1] F. M. Van Tuyl, *Elements of Petroleum Geology*, 1st ed. (Petrol. Pub. Co. of Colorado, 1924), pp. 45-46.

[2] J. S. Irwin, "Faulting in the Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 2 (February, 1926), pp. 111-12.

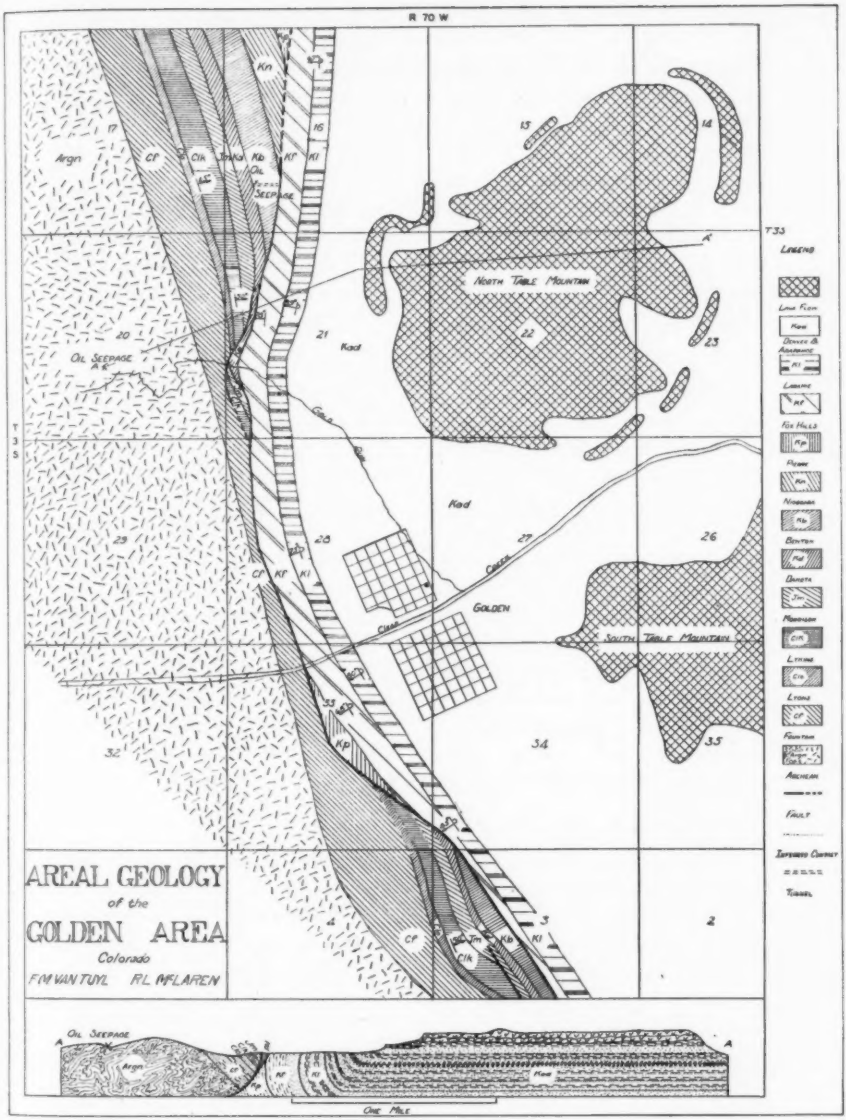

FIG. 1.—Areal geology of Golden area, Jefferson County, Colorado, showing location of oil seepage in pre-Cambrian rocks in Gold Run Creek. Width of area mapped, 3½ miles.

the fourth cycle or perhaps even of the fifth cycle. In other words, the less resistant sedimentary rocks of the Foothills area possess a more complete record of the physiographic history than the more resistant pre-Cambrian crystalline rocks which show only meager evidences of the intermediate stages.

The hogbacks so characteristically developed over the more resistant formations of the Foothills are not present directly east of the seepage because the ridge-forming formations have nearly all disappeared as a result of reverse faulting in this area. However, they reappear about a mile northeast of the seepage and 4 miles southeast of it.

STRATIGRAPHY

The accompanying stratigraphic table gives briefly the character and thickness of the individual formations of the Golden area.

It will be noted that the oldest sedimentary formation of the area is of Fountain age. This deposit is of continental origin and is usually referred to the Pennsylvanian system. Succeeding the Fountain are the Lyons, Lykins, Morrison, and Dakota formations, also representing fresh-water and perhaps in part eolian deposits. The Benton, Niobrara, and Pierre formations are distinctly of marine origin, while the Laramie and Fox Hills contain brackish-water faunas. The Arapahoe and Denver formations, which were formerly thought to be separated from the Laramie by a pronounced unconformity, are now believed to be closely related to the Laramie and are correlated with the Lance series of the northern Rocky Mountain region. They represent alluvial-fan deposits formed by streams flowing eastward from the older rocks whose uplift undoubtedly began prior to Laramie time.

STRUCTURAL GEOLOGY

The Front Range of Colorado represents a great anticline, the eastern limb of which is locally modified by *échelon* folds and reverse faults. The anticline has been deeply dissected during repeated uplifts. Remnants of at least three erosion surfaces are preserved. Two of these are within the range and the third forms shelves and other remnants along its eastern margin. Although there is evidence that the uplift of this great anticline began in pre-Laramie time, it has been definitely established that the movement attained its maximum development in post-Denver time, inasmuch as this formation is involved in the intense deformation of the Foothills belt.

In the Golden area this post-Denver uplift, which is correlated with the Laramide revolution, was accompanied by reverse faulting, which

STRATIGRAPHIC TABLE

Age	*Group and Formation*	*Character*	*Thickness (Feet)*
Recent		Gravels along streams	
Quaternary		Alluvium and terrace gravels	
Cretaceous	Denver	Interbedded sandstone, conglomerate boulder beds and clay; chiefly andesitic débris	950
	Arapahoe	Sandstone, conglomerate, and clay	800
		Disconformity	
	Laramie	Sandstones, shales, clays, and lignite seams	600±
	Fox Hills	Gray sandy shales and shaly sandstones weathering buff	800±
	Pierre	Lead-gray shales, sandy near top. Thin lenticular limestone and sandstone layers	4,500±
	Niobrara	Gray limestone below, overlain by gray calcareous shales	450
	Benton	Dark, lead-colored carbonaceous shales	400
	Dakota	Hard, massive sandstones with thin seams of clay	75
		Conglomerate at base, hard massive sandstones, sandy shales, and fire clays above	190
		Disconformity	
Jurassic	Morrison	Variegated green-gray and maroon shales with lenticular limestones and sandstones	180
		Disconformity	
Permian	Lykins	Brick-red sandy shales and sandstones with thin limestone and gypsum beds in lower portion	600
Pennsylvanian	Lyons	Massive cross-bedded, cream-white sandstone	200
	Fountain	Red arkosic sandstones and conglomerates with interbedded red shales	1,200+
		Unconformity	
Archean		Gneisses and schists with granite and pegmatite intrusions	

resulted in a displacement of more than 1 mile. The geologic map of the area does not reveal evidence of important bulging of the crystalline rocks toward the east in the area of maximum displacement along the fault. Conversely, there is a bulging of the late Cretaceous deposits lying east of the fault, including particularly the Foxhills, Laramie, Arapahoe, and Denver formations, toward the west. This situation leads

the writers to believe that underthrusting of the younger sedimentary rocks westward has probably been more important than the overthrusting of the pre-Cambrian crystalline rocks and late Paleozoic sedimentary rocks eastward. The structural cross section accompanying the paper is based on the newer interpretation of the structural relations in the Golden area. Credit for the recognition of reverse faulting in the Foothills belongs to Ziegler.[1]

A considerable degree of brecciation appears along the fault at the points where it can be observed. The brecciated zone is in many places as much as 100 feet wide. Wedges of variable width of formations far out of their normal stratigraphic position occur along the fault where it is compound in character, as at the point where it crosses Gold Run. Furthermore, there are important discordances in strike and dip on the two sides of the fault. In the area represented by the accompanying geological map, the formations west of the fault zone show the normal easterly dip averaging between 45° and 50°, but those immediately east of the zone are everywhere overturned. Owing to the highly disturbed character of the fault zone, it is not possible from the study of the fault along the outcrop to determine definitely its hade, and for this reason it is not possible to state whether the fault surface dips westward at a high or a low angle.

The maximum displacement of the fault seems to be in the area between Gold Run and Clear Creek. It is apparent that the Dakota sandstones and associated sedimentary rocks have been thrust under the crystalline rocks for several thousand feet in this area. Inasmuch as the upper sandstone member of the Dakota group has an oil seepage in the tunnel of the Denver Fire Clay Company mine about 1¼ miles northeast of the seepage in the gneiss, and as there are oil residues in the sandstone members of this formation both on Ralston Creek about 3½ miles north of the seepage, and south of Turkey Creek about 11 miles a little east of south of the gneiss seepage, it is believed that the oil which has risen through fissures or other lines of weakness in the gneiss has been derived from the Dakota. It will be recalled that there is commercial oil production from the Muddy sand, generally regarded as the upper member of this group, in the Fort Collins and Wellington oil fields in north-central Colorado, and a small amount of oil has been produced from joint planes in the Pierre shale in the semi-commercial Boulder oil field.

[1]Victor Ziegler, "Foothills Structure in Northern Colorado," *Jour. Geol.*, Vol. 25 (1917), pp. 715-40.

The question arises as to the possibility of oil being trapped in commercial quantities in the Muddy or Dakota sandstone below the fault in this area. No opinion is ventured on this point. However, the drilling of a test well would not be justified without core drilling first being undertaken in order to determine the dip of the fault surface and also the attitude of the formations beneath the fault. With these data in hand, it would be possible to predict with a much higher degree of accuracy than at present the most feasible location for a test well and the depth of drilling required to test the Dakota group beneath the fault.

OCCURRENCE OF OIL IN BASALT DIKES IN SOUTHERN COLORADO

Huerfano County.—In the Walsenburg folio Hills[1] makes the following statement.

> About two miles north of the Huerfano River near the west boundary of the quadrangle, there are two small dikes of dark-colored basalt. At the point where they cut through the bituminous material of the Apishapa formation [the upper member of the Niobrara chalk of Upper Cretaceous age] the cavities in the dike rock afford sufficient crude petroleum to soil the hand when the rock is freshly broken. The supposition is that the oil has resulted from the action of the lava at a high temperature on the adjacent bituminous matter and that at other points where the same formations are cut by larger and more numerous bodies of eruptive rock the same process may have operated on a more extensive scale.

According to H. W. C. Prommel,[2] this locality is in Sec. 34, T. 26 S., R. 68 W. He reports that the dikes are narrow and parallel, and have a northwest-southeast trend. The oil, which is light green, attains the greatest saturation in the centers of the dikes.

Another dike which contains oil in joints cuts the Graneros shale, of Upper Cretaceous age, northeast of Rattlesnake Butte, T. 26 S., R. 63 W.

Las Animas County.—A. E. Brainard[3] has observed oil in a basalt dike about 8 miles west of Trinchera in Las Animas County. He advises that two parallel basaltic dikes having a nearly east-west trend cut the Niobrara and Pierre formations of Upper Cretaceous age a short distance north of the Colorado-New Mexico boundary, in the northeastern portion of T. 35 S., R. 61 W., and the northwestern portion of the next township east. The distance between the dikes is about 14 feet. The southernmost dike, which is about 3½-4 feet in width, is vesicular, and the open-

[1] R. C. Hills, *U. S. Geol. Survey Folio 68* (1900), p. 6.

[2] Oral communication.

[3] Oral communication.

ings are filled with green oil. The northernmost dike, however, is compact and contains no oil. The Upper Niobrara (Apishapa shale) is gray, calcareous shale that locally shows oil in distillation tests. The oil is found only where the oil-bearing dike cuts this shale.

Höfer[1] refers to the presence of oil in a ferromagnesian dike near Aguilar. There are undoubtedly several other occurrences of this type in this and near-by counties.

Archuleta County.—The occurrence of oil in dikes near Pagosa Springs, Archuleta County, is in a belt of folded Cretaceous strata on the west flank of the Conejos Range. This has been examined by R. Clare Coffin, chief geologist of the Midwest Refining Company, who was kind enough to furnish the following brief statement on the subject.[2]

> The dike rocks are of vesicular basalt standing almost vertical and cutting beds of Mancos shale. A light oil is often found in the amygdaloidal cavities. Field study by Clarence B. Osborne and myself leads us to believe that the oil-bearing portion of the zone is limited to the zone which was in contact with the Mancos shale. Similar dikes crossing the Dakota were studied by Osborne, but he found no traces of oil.

There seems to be general agreement among the geologists who have examined the petroliferous dikes in Colorado that the oil has resulted from the distillation of organic matter in the intruded shales by the heat given off from the igneous intrusions which penetrated them.

[1]H. Höfer, *Das Erdöl und seine Verwandten*, 4th ed. (1922), p. 175.

[2]Arthur Lakes, "Oil-Impregnated Volcanic Dikes in Colorado," *Mines and Minerals*, Vol. 25 (1905), p. 394.

Clarence B. Osborne, "A Theory to Account for Occurrence of Oil in the Vesicular Cavities of Igneous Intrusions," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 3 (May-June, 1923), pp. 288-90.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 8 (AUGUST, 1932), PP. 777-785, 3 FIGS.

OCCURRENCE OF OIL IN METAMORPHIC ROCKS OF SAN GABRIEL MOUNTAINS, LOS ANGELES COUNTY, CALIFORNIA[1]

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ABSTRACT

An occurrence of nearly water-white light-gravity oil obtained from wells drilled into metamorphic rocks on the north side of the San Gabriel Mountains, Los Angeles County, California, has been of interest to geologists for many years. The metamorphic rocks are in fault contact with sedimentary rocks, those at the surface being of late Pliocene and Pleistocene age. From a detailed study of the geology of this region the conclusion is reached that the oil has migrated in Eocene strata underlying the Pliocene and migrated along faults to its present position in the crystalline rocks. Filtration taking place during this migration is thought to have been competent to produce this light oil having a high percentage of aromatic hydrocarbons.

Six wells drilled between 1899 and 1901 in Placerita Canyon, near Newhall, Los Angeles County, California (SE. corner of NE. ¼ of Sec. 4, T. 3 N., R. 15 W., S. B. B. and M.) are of particular interest to those studying the occurrence of oil, due to the fact that they are located, for the most part, in the metamorphic rocks of the San Gabriel Mountains. They formerly produced small quantities of light-gravity, almost water-white oil from this formation. Neither of the two wells now capable of yielding oil is commercially productive. One is shut in and the other is open and flowing a small amount of gas with about a gallon per day of fluid of which not more than about 15 per cent is oil. In addition, several unsuccessful tests have been drilled in this vicinity at various times.[3] All the wells were drilled with cable tools, and logs which might have any geologic value are not available. The most northerly of this group of six wells was drilled practically on the fault contact between the metamorphic rocks of the San Gabriel Mountains on the south, and

[1]Published by permission of G. C. Gester, chief geologist, Standard Oil Company of California. Manuscript received, June 23, 1931.

[2]Standard Oil Company of California.

[3]G. H. Eldridge and Ralph Arnold, "The Santa Clara Valley, Puente Hills, and Los Angeles Basin Oil Districts, Southern California," *U. S. Geol. Survey Bull. 309* (1907), p. 100.
W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924), pp. 155-56.

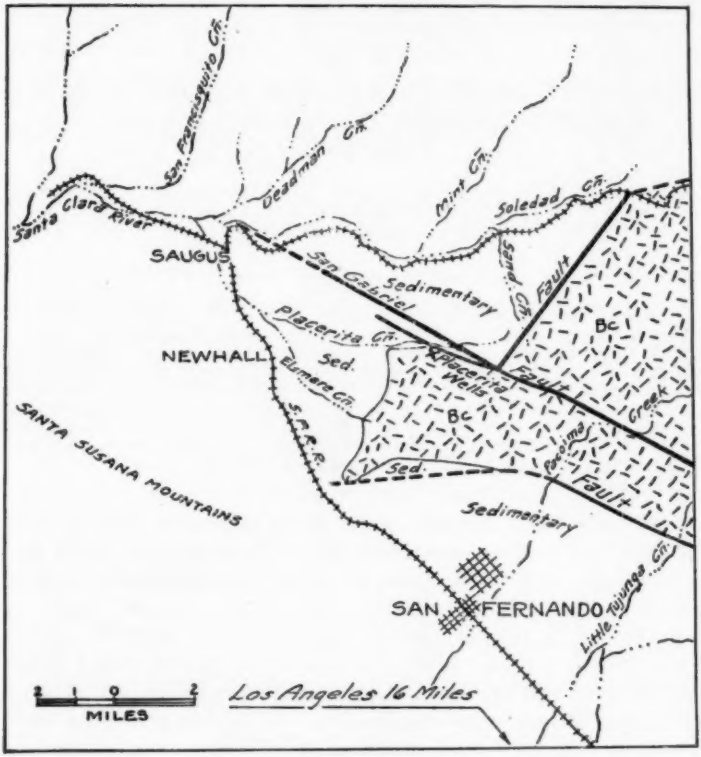


FIG. 1.—Generalized map showing location of Placerita Canyon wells with respect to Basement complex and sedimentary rocks.

the Saugus formation (Pleistocene) on the north. The other five wells were located within the area of metamorphic rocks.

The "Basement complex" of the San Gabriel Mountains consists of schists, gneisses, and various types of igneous rocks. In the immediate vicinity of the Placerita wells schists predominate, but no attempt has been made to classify the various rock types.

The oldest post-crystalline rocks known in the district are Eocene shales, sandstones, and conglomerates correlated with the Domengine formation, which crop out near by in Elsmere Canyon.[1] The closest

[1] W. S. W. Kew. Paper read before Geology and Paleontology Club, California Institute of Technology, March 31, 1931.

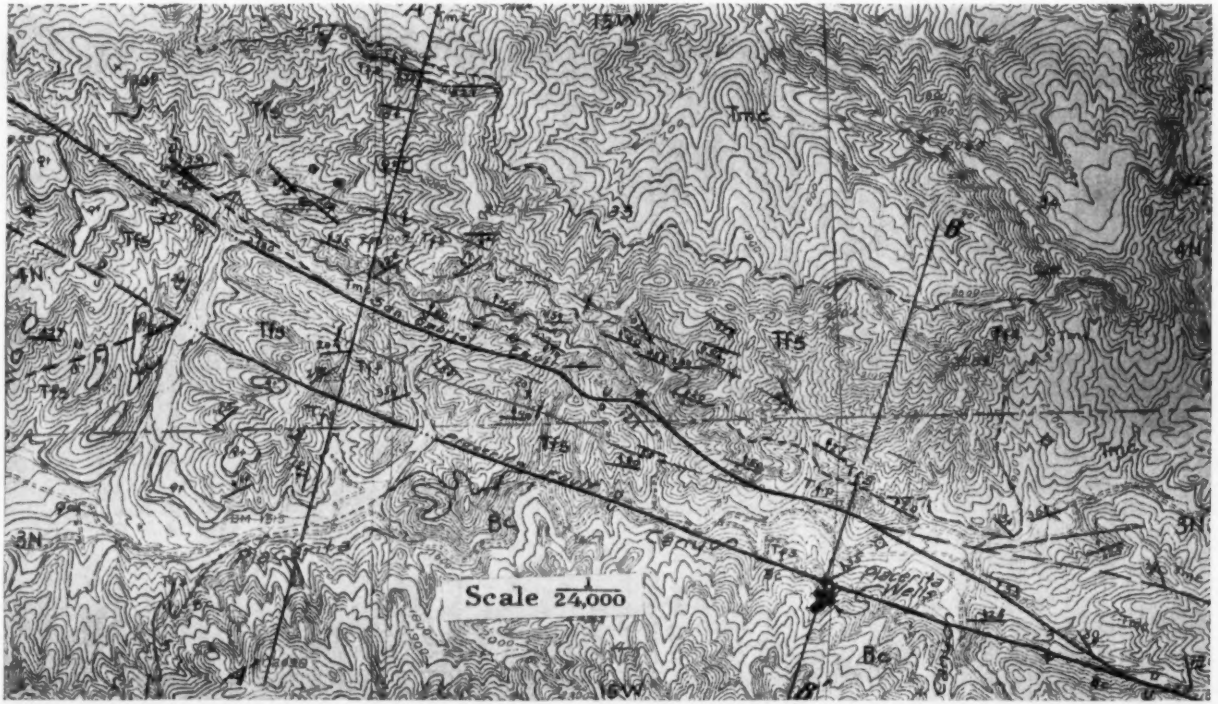


FIG. 2.—Geologic map of Placerita Canyon in vicinity of wells. *Ec*, Basement complex; *Tmc*, Mint Canyon formation (upper Miocene); *Tfp*, Pico formation (upper Pliocene); *Tfs*, Saugus formation (Pleistocene); *Qt*, Quaternary terrace deposits; *Qal*, Quaternary alluvium.

known occurrence to the Placerita wells is in Sec. 31, T. 4 N., R. 15 W., where a well recently drilled cored hard sand and conglomerate of probable Eocene age. As the Eocene is known to have a wide distribution in this general region it is considered very probable that these rocks underlie the later sedimentary rocks on the north side of the San Gabriel Mountains. Eocene rocks yield oil in natural seepages and in small quantities from wells in the Newhall district. For this reason their presence in the Placerita region is important.

The Mint Canyon is the oldest sedimentary formation exposed in the area shown on the map. It consists of non-marine sands, gravels, and clays of upper Miocene age.[1] It is known to lie beneath beds containing fossils of Santa Margarita age (upper Miocene) and has yielded a vertebrate fauna, the age of which is considered to indicate the middle part of the upper Miocene.[2] It contains no beds considered to be a source of oil, nor has any oil ever been found in it.

The Mint Canyon formation is unconformably overlain by beds consisting principally of coarse sandstone, conglomerate, and silty sand of marine origin, which are correlated with the Pico formation (upper Pliocene) as exposed in Elsmere Canyon.[3] The only fossils found in the Pico of the Placerita Canyon area occur in a lenticular outcrop in the northwest corner of Section 33, where it consists of massive, light gray, fine, silty sand, locally containing scattered boulders some of which are several inches in diameter. This outcrop is on the north limb of a syncline, whereas the corresponding position on the south limb is occupied by coarse sandstone and conglomerate. At localities beyond the limits of this map, similar beds directly overlie the fine silty sand. On this basis as well as that of lithologic similarity the beds cropping out along the southern limb of the syncline are classed as Pico, although fossils are lacking. The dissimilarity of the Pico on the opposite limbs of the syncline may be explained by the unconformable contacts both with the Mint Canyon below and the Saugus above (Fig. 3, Section *AA'*). The relatively thin series of silty, gray sands was probably never deposited in the area now occupied by the southern limb of the syncline, whereas on the northern side, the overlying sandstones and conglomerates

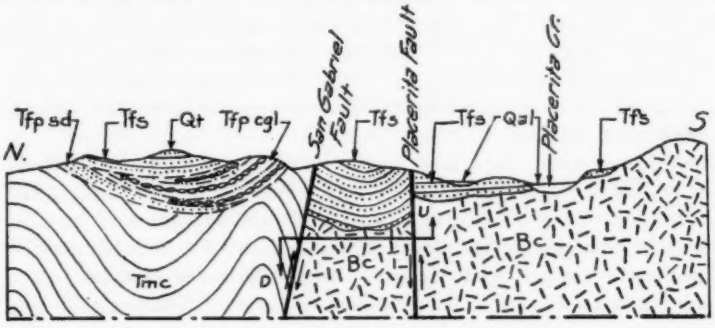
[1] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles Basin and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924), pp. 52-55.

[2] J. H. Maxson, "A Tertiary Mammalian Fauna from the Mint Canyon Formation of Southern California," *Carnegie Institution of Washington Pub. 404* (August, 1930), pp. 77-112.

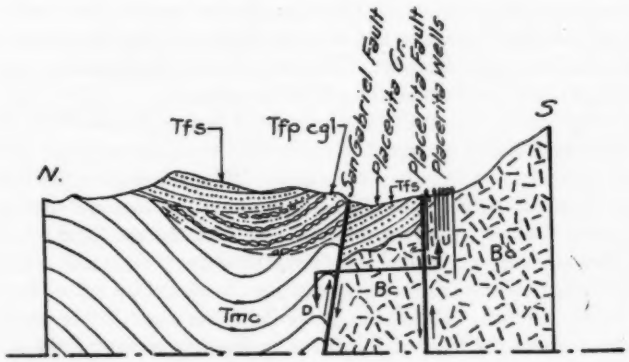
[3] W. S. W. Kew, *op. cit.*, p. 70. Recent work shows all the lower Pliocene to be absent.

were eroded before the deposition of the Saugus. The unconformity between the Pico and Mint Canyon is well exposed in the western half of the area mapped, where nearly vertical beds of Mint Canyon crop out between the cliffs formed by the Pico conglomerates, and the San Gabriel fault.

The Pico formation is unconformably overlain by the non-marine clays, sands, and gravels of the Saugus formation (Pleistocene).[1] Cer-



SECTION A-A'



SECTION B-B'

SCALE:-1"= 2000'

FIG. 3.—Structure sections *AA'* and *BB'* across Placerita Canyon.

[1] W. S. W. Kew, *op. cit.*, p. 81. Recent work has shown that the Saugus is entirely of Pleistocene age.

tain clay beds of the Saugus are similar to those of the Mint Canyon, and there are conglomerate beds closely resembling the Pico but differing chiefly in a less degree of induration. Where the unconformable relationship is not distinct it may be difficult or impossible to map the contacts accurately. The lower part of the Saugus is characterized by the presence of dark greenish brown and olive-green beds of sand and gravel, in contrast to the lighter tan, white, or bluish sands, clays, and conglomerates above. The general absence of the lower "green" series on the north side of the San Gabriel fault suggests that this area may have been somewhat higher than that immediately south of the fault, at the time the Saugus was laid down. The Saugus is locally overlain by nearly flat terrace deposits, which are extensive a short distance west of the area mapped.

The dominant structural feature of the area is the San Gabriel fault, which strikes approximately N. 65° W., and, at least locally, dips steeply north. About ¼ mile farther south, and approximately parallel with it, is another fault, called for convenience the Placerita fault, which marks the contact of the Saugus with the Basement complex in the eastern half of the area. It can be followed for some distance west where it brings the lower "green" beds of the Saugus formation into contact with the upper, lighter beds. Several smaller faults have been mapped but are of little importance. The Placerita fault, the plane of which dips nearly vertically, is well exposed in cuts on the old road leading from Placerita Canyon to the three southerly wells of the group drilled into the metamorphic rocks. The fault passes practically through the location of the most northerly well in the group.

The north side of the Placerita fault is downthrown with respect to the south side; the movement probably does not exceed a few hundred feet, and occurred in post-Saugus time. This is shown by the fact that the Saugus formation was affected by the movement, and also by the absence of older sedimentary formations between the Saugus and the Basement complex. Unless older formations are present and completely overlapped by the Saugus, which is not considered probable, the block between the San Gabriel and Placerita faults must either have been entirely above the limit of deposition during Miocene and early Pliocene time, or at least have stood sufficiently high to allow these formations to be removed by erosion before the deposition of the Saugus. The presence of the Mint Canyon and Pico formations north of, and ter-

minating along, the San Gabriel fault, on the other hand, shows that this area was downthrown at least as early as Miocene time, and although Eocene rocks do not crop out, it is probable that rocks of that age underlie this area as they do the area farther south.

In post-Saugus time, however, and probably during the time that the Placerita fault was active, the movement on the San Gabriel fault was reversed. It is possible that the block between the San Gabriel and Placerita faults moved down as a unit, forming a graben, and that little or no relative movement occurred between the block north of the San Gabriel fault and that south of the Placerita fault; or even that the north block moved downward with respect to the south block, though upward with respect to the intervening "graben block."

The sedimentary rocks on the north side of the San Gabriel fault are folded into a syncline. It is evident that folding was in progress during Miocene and lower Pliocene time, as well as in late Pliocene and Pleistocene, for the beds of the Mint Canyon are much more sharply folded near the San Gabriel fault than those of the Pico, and the Pico, in turn, more sharply than the overlying Saugus.

The Saugus beds between the San Gabriel and Placerita faults are folded into a gentle syncline in the western part of the area. This structure does not continue throughout the eastern part of the area, apparently striking into the San Gabriel fault.

It is evident from the foregoing brief description of the contiguous formations, that neither the non-marine Mint Canyon and Saugus formations, nor the coarse sandstones and conglomerates of the Pico formation, could be a source of petroleum. Formations of Eocene age are considered to be the source of oil in several California fields, including Simi (Tapo Canyon), Bardsdale, Goleta, Sespe Canyon, Shields Canyon, South Mountain, and Torrey Canyon. At Elsmere Canyon live oil seepages occur in outcrops of the Eocene, and this formation undoubtedly is the source of oil obtained from the Pliocene in this vicinity. As previously noted, it is probable that the Eocene underlies a considerable area on the north side of the San Gabriel fault, as well as areas west and south of that mapped, and it seems logical to consider that this series might be the source rock for any oil found in the vicinity.

Although it is beyond the scope of this paper to disprove the possibility that oil originated through some process such as that proposed

by White[1] or Rich[2] from sedimentary rocks now incorporated in the schist, this mode of origin is not thought to be probable, due to the highly metamorphosed condition of the rocks in the vicinity, which here consist of "hornblende schist intruded by aplite dikes."[3]

Oil originating in the Eocene may have migrated along the San Gabriel fault into the Saugus beds on the graben block and thence up the dip (Fig. 3, Section *BB'*) to the Placerita fault. It is possible that such migration occurred before the movement on the Placerita fault was complete, and took place chiefly near the contact of the Saugus and the underlying crystalline rocks. Filtration through fine sand and clay beds of the Saugus as well as through gouge developed along the Placerita fault may account for the peculiar character of the oil, for, according to Prutzman,[4] filtration through such material is competent to produce this type of oil. It is even conceivable that heat generated by movement along the Placerita fault may have resulted in increased pressures and thus have produced somewhat the effect of filtering under pressure.

A sample of oil from the most northerly well was recently analyzed. This sample was kindly furnished by F. E. Walker, the present owner of the property, and was typical of oil from this group of wells, excepting that it had remained in open storage for some time, giving an opportunity for evaporation of some of the lighter fractions. The data tabulated on the following page were obtained.

The high percentage of aromatics, the low percentage of unsaturated hydrocarbons as shown by absorption in H_2SO_4, low sulphur content, and absence of heavy ends are the outstanding chemical characteristics of the oil. However, G. J. Ziser, who made the analysis, does not believe that the character of the oil in itself furnishes sufficient evidence on which to base an opinion as to its origin, inasmuch as any process that would result in a concentration of lighter fractions might be responsible for the formation of an oil of such character. The recently published work of Brooks[5] is of particular interest in this regard. He concludes

[1]David White, "Late Theories Regarding Origin of Oil," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 723-34.

[2]John L. Rich, "Generation of Oil by Geologic Distillation During Mountain Building," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 11 (November, 1927), pp. 1139-49.

[3]W. S. W. Kew, *op. cit.*, p. 156.

[4]P. W. Prutzman, "Petroleum in Southern California," *California State Min. Bur. Bull. 63* (1913), p. 177.

[5]Benjamin T. Brooks, "Chemical Considerations Regarding the Origin of Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 6 (June, 1931), pp. 611-27.

that "The presence of benzene hydrocarbons in petroleum can be accounted for by disproportionation reactions at low temperatures," and mentions recent unpublished work in which he has shown that fuller's earth is capable of causing such reactions. He further cites experiments performed on various minerals and sedimentary rocks showing that many of these have properties generally supposed to be characteristics of fuller's earth, particularly that of causing polymerization.

A. P. I. gravity	37.7
Flash (closed Tag.)	73
Color Saybolt	+5
Sulphur	0.10
Aromatics	52.5 by weight
Refractive index at 20° C.	1.4696
Absorption in sulphuric acid	3 per cent

A. S. T. M. Distillation

Start	245 degrees
5 per cent	272
10	283
20	298
30	317
40	337
50	361
60	391
70	428
80	464
90	513
End point	594
Per cent recovered	98

If, on a basis of chemical analysis, however, the possibilities of formation by filtration and of formation by natural distillation from organic material in sediments now lithified are both admitted; from the facts that (1) neighboring areas are underlain by Eocene sediments, the source of petroleum at localities within a few miles, as well as elsewhere in California, (2) that so far as known production was limited to an area closely adjacent to a fault forming the contact between sedimentary and metamorphic rocks, and (3) that the crystalline rocks are intruded by igneous dikes and are highly metamorphosed, the conclusion is reached that the theory of filtration offers the more plausible explanation.

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VOL. 16, NO. 8 (AUGUST, 1932), PP. 786-796, 2 FIGS.

OIL SEEPAGES IN BELT SERIES OF ROCKY MOUNTAINS NEAR INTERNATIONAL BOUNDARY[1]

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ABSTRACT

Oil seepages issuing from pre-Cambrian rocks thrust over Mesozoic rocks within the Rocky Mountains near the 49th parallel are described. The problems of source beds and reservoir rock are discussed, also brief mention of the structure giving rise to these seepages is made. Upper Paleozoic dolomites and limestones are suggested as source beds and as suitable reservoir rock. The Jurassic and Colorado shales are also suggested sources of hydrocarbons. Overthrusting and underthrusting are postulated.

INTRODUCTION

This discussion deals with certain oil seepages occurring in pre-Cambrian and Cambrian rocks of the Clarke and Lewis ranges of southwestern Alberta, southeastern British Columbia, and northwestern Montana, near the International Boundary. The Clarke and Lewis ranges, the most easterly segment of the Rocky Mountains, are bounded on the east by the Foothills Belt and on the west by the Flathead valley or trench. Oil seepages issuing from pre-Cambrian and adjacent rocks are found at Cameron Brook in Waterton Lakes National Park, and on the western edge of the Clarke Range along Sage Creek, British Columbia, and Kintla Lake, Glacier National Park (Fig. 1). Much has been written regarding these seepages in the publications of the Geological Survey of Canada.[3] Shallow holes have been sunk at and near these

[1]Abridged from paper read before the Association at the San Antonio meeting, March 21, 1931. Revised manuscript received, November 1, 1931. Published by permission of O. B. Hopkins, chief geologist, Imperial Oil, Ltd., Toronto, Ontario.

[2]Geologist in charge, Imperial Oil, Ltd., 606 Second Street, West.

[3]R. A. Daly, "North American Cordillera at the 49th Parallel," *Geol. Survey of Canada Mem. 38* (1921), pp. 90-95.
J. D. MacKenzie, "Geology of the Flathead Coal Area," *Geol. Survey of Canada Mem. 87* (1916).
D. B. Dowling, "Review of Prospecting for Oil on the Great Plains," Lewis and Clarke Ranges, Rocky Mountains," *Geol. Survey of Canada Summary Rept., Pt. B* (1920), pp. 16-22.
Ralph Arnold, "Report on the Oil Possibilities of the Flathead District, B. C.," *Bur. of Mines Province of British Columbia Ann. Rept.* (1914), pp. 238-42.
F. G. Clapp, "Petroleum and Natural Gas Resources of Canada," *Canada Dept. of Mines, Mines Branch Pub. 291*, Vol. 2 (1915).
G. S. Hume, "Oil and Gas in Western Canada," *Geol. Survey of Canada Econ. Geol. Ser. 5* (1928).

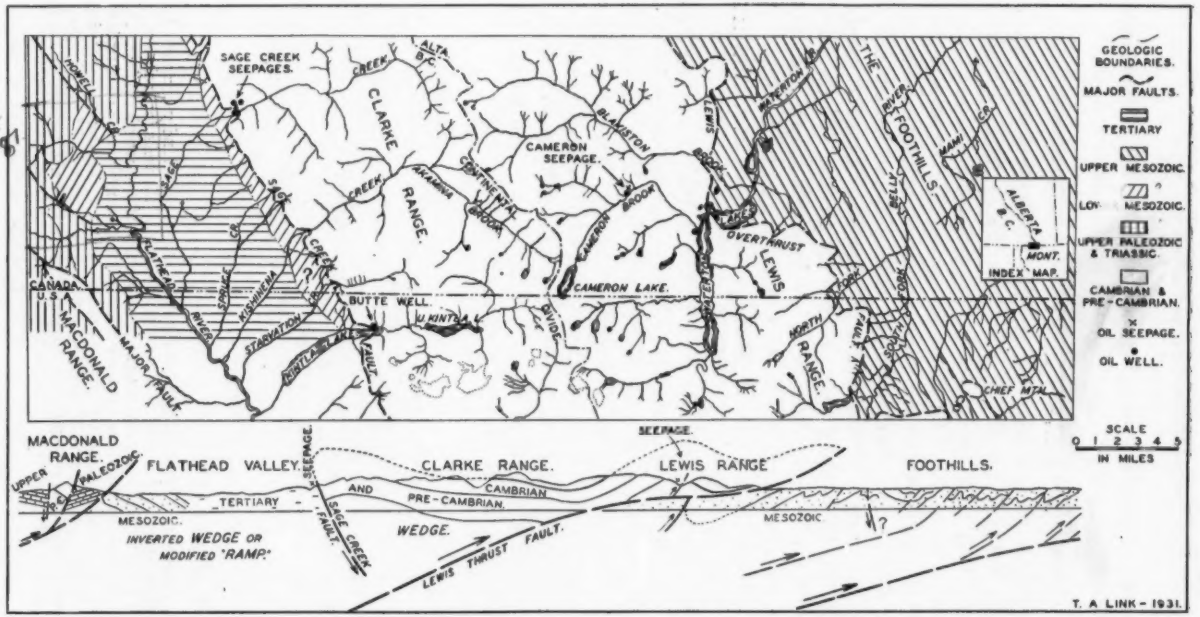

FIG. 1.—Generalized geologic map of Lewis and Clarke ranges at the 49th parallel, showing location of oil seepages in Belt series. Also cross section in which Flathead valley is interpreted as an "inverted wedge" or modified "ramp," and Lewis and Clarke ranges as bounded by *underthrust* on west and Lewis *overthrust* on east side. (Data from R. A. Daly, J. D. MacKenzie, J. S. Stewart, D. B. Dowling, and others, with modifications and additions by writer.)

seepages, and have had encouraging showings of oil, but no commercial production.

DESCRIPTION OF SEEPAGES AND BRIEF DRILLING HISTORY

Cameron Brook seepages.—The seepages at Cameron Brook are in the Clarke Range of the Rocky Mountains (Fig. 1) at an altitude of 5,000 feet. They reach the surface through drift and gravel which mantles the Altyn formation of the Upper Belt series. The presence of these seepages has been known for many years, and their origin has led to considerable speculation. Previous to any drilling at this locality one of the prospectors used to extract oil from the seepages by means of "gunny-sacks" (burlap bags) which were placed in the pits dug into the gravel or surface drift. The oil absorbed by the bags was squeezed out and hauled in wooden barrels to Pincher Creek, Alberta, for local use. A recently constructed auto road (Akamina trail) leads from Waterton Lakes to these seepages.

An account of the early days of drilling in this vicinity may be found in Dowling's report on this area.[2] This account shows conclusively that oil was encountered in some of the shallow drill-holes, but possible commercial production in this vicinity is doubtful. The oil obtained from the seepages and wells near Cameron Brook is dark green and has a gravity of about 30° Bé. In the deeper wells the drill passed from pre-Cambrian rocks through the Lewis overthrust fault into Cretaceous rocks[1] (Colorado shale or Crowsnest volcanics).

Depth in Feet	
86	Gray shale
677	Very siliceous dolomite
730	Greenish gray and purple shale
1,205	Dolomite
1,208	Gray shale, yields oil by distillation
1,233	Gray dolomite
1,380	Shale, mostly gray
1,513	Alternating gray shale and sandstone
1,614	Gray sandstone
1,753	Green-gray shale

[2]D. B. Dowling, *op. cit.*, pp. 18-20.

[1]W. A. Johnston, of the Geological Survey of Canada, very kindly arranged for the re-examination by F. J. Fraser of the samples of one of the wells for inclusion in this paper. The lithological determinations from a study of 256 samples follow. No micro-fossils were noted and the lower shale and sandstone samples showed abundant slickensiding, especially at 1,250 and from 1,614 to 1,753 feet. The samples recorded as sandstones are very fine-grained and are not easily distinguished from those recorded as shale. Insoluble residues of the shales show a very dense material of indefinite character.

Johnston writes as follows.

The lower sandstones and shales are suggestive of the Crowsnest volcanics rather than the Benton or the Belly River. Hume thinks that they are the volcanics. The oil-bearing shale at 1,205-1,208 feet may be something different. J. S. Stewart's map of the area ("Geology of the Disturbed Belt of Southwestern Alberta," *Geol. Survey of Canada Mem. 112*, 1919) shows the Belly River as extending east of the outcrop of the thrust fault. The volcanics may be badly sliced by thrust faulting and be underlain by the Belly River.[1]

Sage Creek seepages.—The less accessible seepages observed by the writer along Sage Creek, British Columbia (Fig. 1) are larger and the oil of a higher grade and lighter color than that at Cameron Brook. The oil has an average gravity of 44° Bé., is transparent, and has a straw or amber color. In one well was found oil of about 60° Bé. gravity, almost colorless with a bluish tinge resembling pure "water-clear" naphtha. It could easily be mistaken for "discolored"[2] crude naphtha from the Turner Valley field. One of the seepages appears to be capable of producing about one barrel of oil per day. The rocks at Sage Creek belong, according to Daly, to the Appekunny formation of Lower Cambrian age, or, according to Willis, of Algonkian age.

The structural significance of these three seepages is that they occur east of the west-facing Cambrian scarp of the Clarke Range, near their (fault) contact with the younger rocks of Flathead valley. Other seepages are found along Kishenehn Creek, British Columbia, and lower Kintla Lake, Montana, along the same fault. Their alignment suggests a fault of great displacement and high dip along the western scarp of the Clarke Range.

A discussion of the origin of these oil seepages must take into consideration the following problems: (1) the original source beds which gave rise to the hydrocarbons; (2) the reservoir rock from which the present seepages are fed; (3) the structure of the rocks which makes it possible for the oil to reach the surface; (4) the differences, color, et cetera, of the oil from the two groups of seepages.

PROBLEM OF SOURCE BEDS

Pre-Cambrian.—According to Daly,[3] the Belt series, in the vicinity of the Cameron Brook and Sage Creek seepages, consists of thin- to

[1]Letter to Sidney Powers, dated November 6, 1931. These data have just been published: W. A. Johnston, "Deep Borings in the Prairie Provinces," *Geol. Survey of Canada Sum. Rept., 1931*, Pt. B (1932), p. 75.

[2]This term is employed by the operators in Turner Valley and is applied to naphtha which has been colored by coming in contact with darker crude oil.

[3]R. A. Daly, *op. cit.*, pp. 47-95.

thick-bedded, light gray, generally sandy, siliceous magnesian limestone of the Altyn formation, and massive, dark gray "feldspathized" dolomite of the Waterton formation. Examination of these beds at their outcrops and of cores from diamond-drill holes on Cameron Brook shows that the oil occurs in crevices or fractures. This does not preclude the

FIG. 2.—Outcrops of Waterton formation at Cameron Falls in Waterton Lakes Park. A hole sunk on delta of this creek passed from these pre-Cambrian rocks through Lewis overthrust fault into Cretaceous beds.

possibility that these pre-Cambrian sedimentary rocks may, at some time, have yielded hydrocarbons. However, the possibility that the present seepages are fed from source beds within the Belt series is not worthy of serious consideration.

Cambrian.—The Cambrian section consists of a great thickness of siliceous dolomites, magnesian limestones, variously colored argillites and metargillites as well as quartzites, some of which, in their pre-metamorphosed stage, might have contained oil source materials. In their present state they can not be regarded as the source beds for the seepages under consideration.

Upper Paleozoic section.—At and near the 49th parallel, there are no upper Paleozoic rocks exposed in the Lewis and Clarke ranges, but their presence farther west in the MacDonald Range, the Flathead valley, as well as farther northward, merits their consideration as a possible

source rock for the seepages which are found in the Clarke Range. Devonian, Silurian, and Carboniferous limestones, dolomites, and shales which, in the light of recent researches[1] on petroleum source rocks, might readily be regarded as source beds, are widespread in the Rocky Mountains. Much of the Devonian and Carboniferous is limestone and dolomite, highly cavernous, porous, and fossiliferous.

At Turner Valley[2] the production of "wet" (naphtha-bearing) gas in large volumes is confined to limestones and dolomites of Carboniferous age. Although the determination of the precise stratigraphic position of the source beds of the Turney Valley production is questionable, one may safely state that upper or middle Paleozoic and possibly the Jurassic are the main sources.

If the Turner Valley production can be used as a criterion for the seepages in the Clarke Range, it seems permissible to ascribe a possible source for the seepages to middle or upper Paleozoic beds—presumably limestones or dolomites of Devonian or Carboniferous age.

Triassic and Jurassic section.—The great thickness of Triassic and Jurassic beds in the Cordilleran geosyncline was mentioned in a previous paper by the writer.[3] The presence of oil within and directly above the Ellis beds in the Sweetgrass arch oil fields,[4] and the occurrences of gas and oil in the Fernie shale of the Turner Valley field, are highly suggestive of source beds within the Jurassic. The nature of the Fernie and Ellis beds, namely greenish and dark, almost black shales, fossiliferous, with an abundance of pyrite, siliceous and calcareous concretions, glauconite, and limestone lenses, constitutes the writer's conception of a typical source rock. The unconformity between these formations and the Paleozoic rocks, as well as a consideration of the paleogeography during

[1]P. D. Trask, "The Potential Value of Several Recent American Coastal and Inland Deposits as Future Source Beds of Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 11 (November, 1928), p. 1068.

[2]F. H. McLearn and G. S. Hume, "The Stratigraphy and Oil Prospects of Alberta, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 3 (March, 1927), p. 254.

[3]Theodore A. Link, "The Alberta Syncline," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 491-507.

[4]Thomas B. Romine, "Oil Fields and Structure of Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), pp. 779-97.
W. S. Yarwood, "Stratigraphy of Red Coulee Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 10 (October, 1931), pp. 1161-70.
W. F. Howell, "Kevin-Sunburst Field, Toole County, Montana," *Structure of Typical American Oil Fields*, Vol. 2 (Amer. Assoc. Petrol. Geol., 1929).
Eugene S. Perry, "The Kevin-Sunburst and Other Oil and Gas Fields of the Sweetgrass Arch," *Montana State Bur. Mines and Geology Mem. 1* (1928).

Jurassic time, that is, deposition of sediments in more or less protected embayments which had limited circulation with the open sea, is also highly suggestive of source beds for hydrocarbons. Regarding this same matter, Hume and Evans[1] state that

> the character of the Jurassic beds leads to the belief that they are potential source rocks and that the erosional unconformity has been a factor in developing porosity in the upper part of the Paleozoic from which production of gas and oil is secured.

Cretaceous section.[2]—The Blairmore section, of Lower Cretaceous age, in southern Alberta, is composed of sedimentary rocks which have very little resemblance to what is generally regarded as source beds of commercial importance. Light oil and "dry" gas have been produced from the Blairmore and Kootenay of Turner Valley, but this production is generally short-lived. Hume and Evans think that this might be indigenous. In other wildcat tests in the Foothills, similar showings have been encountered in these beds, but none of commercial value. The Blairmore of the Plains area contains oil and gas in the Red Coulee (Border) field,[3] but the source beds could very well be the underlying Ellis shales.

Cunningham Craig[4] ascribes the source of oil in the Foothills and at Cameron Brook to the Kootenay, but this is not the general consensus of opinion among field investigators.[5]

Upper Cretaceous groups which include the Colorado and Montana have yielded essentially no oil in commercial quantities, although dry gas has been produced from the Bow Island gas sand of the Colorado shale. Commercial production of oil from the Colorado shale, which has the appearance of a drained source rock, has not been encountered, and it appears that suitable paleogeographic conditions did not exist throughout wide areas during their deposition in Alberta. Small showings of oil are, however, encountered in the lowermost Colorado of Turner Valley. This oil is the darkest and heaviest encountered in the field. In 1931, a fair showing of oil was obtained in the lower Colorado shale in

[1]G. S. Hume and C. S. Evans, *Geological Survey of Canada*, written discussion of this paper, March 12, 1931.

[2]See Donaldson Bogart Dowling Memorial Symposium, *Stratigraphy of Plains of Southern Alberta* (Amer. Assoc. Petrol. Geol., 1931), 166 pp.

[3]W. S. Yarwood, *op. cit.*, p. 1167.

[4]E. H. Cunningham Craig, "The Oilfields of Alberta," *Jour. Inst. Petrol. Tech. London*, Vol. 16, No. 82 (1930), p. 403.

[5]G. S. Hume, Discussion of E. H. Cunningham Craig's paper, "The Oil Fields of Alberta," *op. cit.*, p. 420.

the Hudson's Bay Oil and Gas Company's Keho Lake well No. 1, north of Lethbridge, Alberta.[1] The Colorado sea was open from the Arctic to the Gulf of Mexico, while shallow embayments or isolated sites of sedimentation with the necessary environment and accumulation of organic débris, appear to have been the exception rather than the rule. Further drilling may, however, disclose suitable paleogeographic conditions in hitherto untested areas. The lower Colorado (equivalent of the Mowry) is the more probable source horizon in this shale. The remainder of the Colorado shale appears to be a very lean source rock. The same may be said for the Pakowki (Claggett), as well as the Bearpaw shale. The interfingering sandstone members of the Colorado and Montana seas, such as the Judith River, Eagle, the Foxhills, and the St. Mary River need not be discussed as source beds.

Tertiary section.—The Tertiary rock column of Alberta consists primarily of fresh-water sandstones and shales. They are essentially all continental sediments deposited above sea-level in flood plains, river beds, and marshes. The nature of these beds in the Plains area precludes any possibility of source beds for petroleum. Curiously, the Tertiary fresh-water lake and delta deposits in the Flathead valley, which consist of coarse gravels, sands and clays, fine-grained, evenly laminated, fossiliferous limestones or marls alternating with fine clay beds and thin lignite seams, are impregnated with

> yellowish, brownish and black material which is thought to be a residue from the evaporation of petroleum. . . . The spheres are thought to represent drops of petroleum that have segregated under the influence of surface tension in the water-saturated rocks, yet were unable to migrate to any considerable distance owing to the very dense character of the enclosing material.[2]

It is possible that this manifestation of petroleum is due to the oil which may have been escaping from the Sage Creek seepages during Tertiary time. The oil may also have been generated in the Tertiary lake and marsh deposits. At any rate these Tertiary deposits (Kishenehn formation) can not be regarded as an adequate source of the Sage Creek seepages.

Conclusions regarding source beds.—Summarizing the aspect of source beds, it seems conservative to state that neither the Tertiary nor most of the Cretaceous section could be regarded as the primary source rock for the Cameron Brook and Sage Creek seepages. The ultimate source beds

[1]Location LSD 2, Sec. 7, T. 11, R. 22, W. of 4th Mer. The well had showings for 50 barrels in the Colorado (Benton) shale from 3,680 to 3,776 feet, and 6 feet below the top of the Madison, the oil with some gas being found at 4,920 feet.

[2]J. D. MacKenzie, *Canada Geol. Survey Mem. 87* (1916), pp. 32 and 33.

for these surface manifestations are in all probability the upper Paleozoic (Devonian, Carboniferous, or both) and possibly the Fernie (Jurassic) beds. Small amounts from the Colorado shale may, however, have been an important factor with respect to the Cameron Brook seepages, as will be pointed out later.

RESERVOIR ROCK

Sedimentary rocks capable of retaining oil or gas in large quantities are present in the geologic column of the outer Rocky Mountain range from the middle Paleozoic up into the Tertiary. Coarse, porous sandstones, many of which are overlain by impervious shales, are common throughout the Tertiary and the Mesozoic strata. Therefore, if sufficient source beds were available, the hydrocarbons generated in them would find ample space in the numerous sandstone layers of the Tertiary and Mesozoic. However, such beds may have acted merely as "carrier beds" as defined by Rich,[1] so that the presence of oil or gas in them would merely be temporary. The same may be said regarding the major and minor faults in this area.

The dolomitic limestones in the upper Paleozoic section (Silurian to Carboniferous) could also serve as excellent retainers for liquid or gaseous hydrocarbons. Turner Valley is an example of such an occurrence. Suitable fracturing or shattering within these dolomites might also enhance their value as reservoir rocks provided there is no chance for escape. Although the pre-Cambrian and Cambrian rocks of the Clarke Range in Glacier and Waterton parks are locally dolomitic, they do not appear to the writer as suitable reservoir rock for the retention of liquid hydrocarbons. The degree of dynamic metamorphism to which they have been subjected is not very much greater than that of the upper Paleozoic section, but alterations by solution and redeposition by circulating waters have left the beds of the Belt series and the Cambrian far too firmly cemented and compact to act as suitable retainers for oil and possibly gas. They may at some earlier geologic date have served as reservoir rocks or carrier beds, but at present they give no signs of having any appreciable amounts confined within them. The pre-Cambrian sedimentary rocks of the Clarke Range are by no means as greatly altered as those of the pre-Cambrian complex found in the Canadian Shield. They still retain their bedding planes and show essentially no schistosity, slaty cleavage, or other features common in areas subjected

[1] John L. Rich, "Function of Carrier Beds in Long-Distance Migration of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931), pp. 911-22.

to intense dynamic forces. In the ranges farther west the metamorphism of these rocks is much greater. Cores from the wells drilled at Cameron Brook and cable-tool cuttings from some of the Sage Creek wells all show dense, hard, massive, well indurated rock which is locally fractured, with stains of oil confined along these fractures.

To summarize, it seems very improbable that oil or gas is retained within the pre-Cambrian and Cambrian rocks of the Clarke Range, but it is probable that it migrated along major and subsidiary faults or fractures through these older rocks from Mesozoic or upper Paleozoic beds which lie beneath the major fault planes, to be described in the following pages.

STRUCTURE

The problem of a structural interpretation which would account for the occurrences of seepages in the Flathead valley and along Cameron Brook involves a commitment of opinion regarding the structure of the Rocky Mountains and the several structural trenches which extend nearly parallel with the grain of the Cordillera. At the present time, as the writer is not prepared to present one chosen structural interpretation, he prefers to postpone this until additional data have been gathered.[1]

The generalized cross section accompanying the map in Figure 1 shows the generally accepted structural interpretation of the Clarke Range and the Flathead valley. According to this, it is clear that migration of oil or gas from Mesozoic or Paleozoic rocks lying below the two main thrust faults could account for the seepages. Migration within the rocks above and below the major fault planes is postulated as having taken place along minor faults and crevices. In this manner it is possible to postulate a Paleozoic source, although Mesozoic rocks were encountered directly beneath the major Lewis overthrust fault.

DIFFERENCE IN PHYSICAL CHARACTER OF OIL

As already stated, the Cameron Brook oil is of a darker brownish color with an average gravity of 30° Bé. while that of the Sage Creek

[1] *Note.* In the original draft, as well as the presentation of this paper at the San Antonio, Texas, meeting of March, 1931, considerable space and time were allotted to a presentation of the structural conditions of the Clarke Range and adjoining areas. A written discussion of the original draft was submitted by G. S. Hume and C. S. Evans of the Geological Survey of Canada in which they expressed their approval, with minor exceptions, of one of the three structural interpretations submitted. At the San Antonio meeting, practically all the discussions centered around the structural problem. At the request of Sidney Powers, editor of this symposium, the chapter on structure has been condensed to a few short statements. A separate contribution by the writer on the structural problem will be prepared in the near future. In this he hopes to make use of the discussion by Hume and Evans.

area is transparent, has an amber color, and a gravity ranging from 44° to 60° Bé. Under the heading "Source beds" it was stated that small quantities of heavier and darker colored oils are encountered in places in the lowermost Colorado shale of Turner Valley and its immediate vicinity. This is the heaviest and darkest oil encountered in that field. Its gravity ranges from about 35° to 42° Bé. Since Colorado shales, or contiguous beds, underlie the pre-Cambrian at Cameron Brook, due to the Lewis overthrust, it is possible that the seepages in this vicinity may, in part, be due to a migration of a limited amount of oil from the base of the shale. There is also the possibility that lighter oils, which have migrated from deeper formations, may have become changed in gravity and color by contamination with small quantities of heavier and darker oil within the Colorado shale.

The color, gravity, and character of the oil from the Sage Creek seepages suggest an origin similar to that of the Turner Valley naphtha. There is a possibility that the hydrocarbons within the underlying porous Paleozoic dolomites might be in a vaporous, or even liquid, state on account of high confining pressures. Decrease of pressure due to fracturing and faulting might change these hydrocarbons to a gaseous state. Contact with obstructions or "baffles," such as surface drift, might cause some of the heavier constituents to be "knocked out" of the gas by a mechanical process similar to that employed in oil and gas separators. If this is the explanation, the principles of the carbon-ratio theory need not be employed to explain the difference in character of the oil in the Cameron Brook and Sage Creek seepages.

CONCLUSIONS

In the light of present knowledge regarding the occurrences of oil and gas in western Canada, the oil seepages in the pre-Cambrian rocks of the Lewis and Clarke ranges may have their origin in upper Paleozoic (Devonian or Carboniferous), Jurassic, or in part in Colorado shale source beds. Upper Paleozoic porous limestones or dolomites may be the reservoir rock, or may have acted as "carrier beds." Migration from these beds to the surface may have occurred along major over- and under-thrust faults or fractures within the pre-Cambrian rocks. These faults and fractures seem to be the determining structural condition. The darker color of the Cameron Brook seepages may be caused by a lower Colorado shale source. If the oil comes from upper Paleozoic rocks it is probably naphtha which has been colored by mixture with oil from lower Colorado shale.

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OCCURRENCE OF BITUMEN IN QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA[1]

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ABSTRACT

Bitumen is found in calcite veins near volcanic rocks and in amygdules in andesite and basalt of Tertiary age on Graham, Tar, and Moresby islands of the Queen Charlotte group.

At Tian Head, on the west coast of Graham Island (about latitude 53° 45′ N., longitude 133° W.), tar and thick black oil exude from white crystalline calcite, which forms a vein or lentil 2-4 inches thick in metamorphosed green siltstone and sandstone. These rocks dip very gently northwest and underlie a horizontal thick sheet of late Tertiary columnar basalt. The bituminous calcite crops out in the form of a vein a few yards long which, in one direction, is covered by the basalt and in the other direction pinches out. Similar, but more irregularly shaped occurrences of bitumen, which are, in most places, associated with some calcite, occur in amygdules 2-3 inches in diameter in the metamorphic rocks, and along fracture planes in the near-by basalt from which the bitumen is separated, according to MacKenzie,[2] by quartz and chalcedony bands.

A few miles east of Tian Head, about 900 feet west of the head of Otard Bay, on the north shore of the bay near low-tide level, similar, though less abundant amounts of bitumen and calcite occur in both igneous and metamorphic rocks. In Otard Bay, however, the outlines of the amygdules in the metamorphic rocks (which dip 15°-40° in both directions away from a small ferromagnesian intrusion near the head of the bay which trends N. 30° E.) prove that they represent casts of ammonoids and pelecypods. Among them are identifiable specimens of *Trigonia*, apparently *T. dawsoni* Whiteaves, a common form in the Cretaceous sedimentary rocks exposed elsewhere on the island. The recognizable fossils at this particular locality contain in their interior tar-soaked siltstone.

[1]Abstracted from observations made in 1929 in company with J. M. Campbell and E. W. Galliher, during the course of investigations carried on for W. E. Dunlap and L. E. Porter, Production Department, Richfield Oil Company of California. Manuscript received, June 4, 1932.

[2]J. D. MacKenzie, *Geol. Survey Canada Summary Rept. 1914*, p. 36; "Geology of Graham Island, British Columbia," *Geol. Survey Canada Mem. 88*, pp. 161-66.

Elsewhere on the island, at Frederick Island, Hidden Creek, King Creek, and the West Fork of Yakoun River, small amounts of black tar and brown oil occur in similar fractured crystalline calcite amygdules and vesicles in metamorphosed, intruded banded argillites of pre-Cretaceous, Mesozoic age. The King Creek and Hidden Creek localities are associated with intrusions of trachyte and andesite; those on the West Fork of Yakoun River are in steeply tilted beds not far from a ferromagnesian intrusion. The more bituminous vesicles occur with bitumen-stained remains of cephalopods, some shattered, some well preserved, which belong to the genus *Arniotites* or to a closely related group.

On the beach at Lawn Hill gummy black tar occurs in the interstices of a fine breccia immediately below basalt flow rock. Farther south, on the east coast of the island, a large specimen of the ammonite, genus *Puzozia*, collected from indurated, basalt-intruded Cretaceous sandstone north of Skidegate Indian Village, on being broken was found to have in the hollow interior irregularly shaped canal-like vesicles carrying brown oil and lined with calcite crystals.

Dawson[1] has recorded the existence of bitumen in agglomerate off the eastern coast of Moresby Island, particularly Tar Island, in the Queen Charlotte group south of Graham Island, but these localities were not visited.

None of the bitumen outcrops on Graham Island is a true hydrocarbon seepage, although the Tian Head occurrence approximates one during the heat of mid-day. The exact chemical composition of these hydrocarbons was not determined.

The nature of the occurrences of the bitumens, and the short time spent in examining them, hardly permit the formation of any hypothesis to explain their origin. MacKenzie, in speaking of the Tian Head and Otard Bay occurrences, concludes that the hydrocarbons were derived from the Maude formation of Jurassic age, at some depth below the lavas, and were brought up in solution by the igneous magmas. He does not mention the outcrops below high-tide level of the fossiliferous Cretaceous sedimentary rocks. MacKenzie and others have emphasized the relation of the tar occurrences and the presence of numerous fossils (referred to as ammonites) in the same or associated rock; it might be well, in addition, to note the close relationship between the tar occurrences, crystalline calcite, and adjacent volcanic activity, and to suggest that some phenomenon analogous to contact metamorphism may have also played some part in the formation of the bitumens.

[1]George M. Dawson, "Report on the Queen Charlotte Islands," *Geol. Survey of Canada Rept. of Explor., Surveys 1878-79*, Pt. 3.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 8 (AUGUST, 1932), PP. 799-808, 6 FIGS.

OIL ASSOCIATED WITH IGNEOUS ROCKS IN MEXICO[1]

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ABSTRACT

Many of the thousands of oil seepages in Mexico are connected with various forms of ferromagnesian igneous intrusions. Most of them occur in the Tampico embayment. The Furbero oil field produces from a laccolith of gabbro and from overlying metamorphosed shale. Igneous activity in the Tampico-Tuxpam region has provided channels along which oil rises to the surface and has furnished the heat which is so characteristic of the oils and oil-field waters of the region. The larger intrusions and the metamorphism of contiguous shales furnished traps as well as channels for migration.

INTRODUCTION

The close association of oil seepages with various forms of igneous intrusives—volcanic plugs and dikes—is of such common occurrence in the Gulf Coastal Plain of Mexico as to be regarded as characteristic, although seepages also occur commonly enough where there is no evidence of intrusive action.[3]

SEEPAGES IN TAMPICO-TUXPAM REGION

The seepages of "chapopote"[4] (heavy viscous oil) occur at or near the contact of the igneous and sedimentary rocks. The obvious and probably true explanation of this association is that the fractured, fissured, and metamorphosed plane of contact provides easy channels of migration along which the oil from deep reservoirs of sedimentary rocks is forced to the surface.

[1]Manuscript received, March, 1932.

[2]Chairman, Amerada Corporation, 120 Broadway.

[3]This subject was discussed by the writer some years ago in: "The Effect of Igneous Intrusion on the Accumulation of Oil in the Tampico-Tuxpam Region, Mexico," *Econ. Geol.*, Vol. 10 (1915), pp. 651-62; and "The Furbero Oil Field, Mexico," *Trans. Amer. Inst. Min. Eng.*, Vol. 52 (1916), pp. 268-80. Several notes kindly furnished by John M. Muir of Fort Worth, Texas, have been added to the manuscript.

[4]In Cerro Azul alone more than 6,000 individual emissions of asphalt have been mapped and counted (some of which are associated with intrusions).

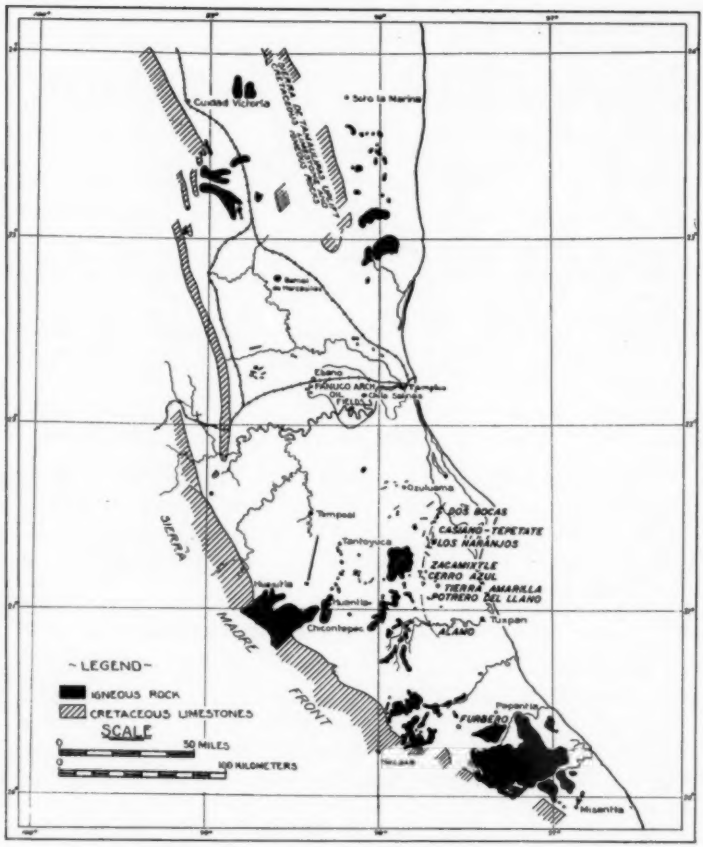

FIG. 1.—Sketch map of Tampico-Tuxpam region, Mexico, showing oil fields, igneous rocks, and Sierra Madre mountain front. Most of the seepages are in a triangular area, defined by a north-south line through Furbero, a line through Tantoyuca and Ozuluama, and the front of the Sierra Madre. It includes the fields of the so-called Golden Lane.

Notable examples of seepages occurring in the contact zone around volcanic plugs or necks are at Cerro de la Pez in the Ebano field; Mata de Chapopote at the common corner of the haciendas La Palma, Salinas, and Caracol (Fig. 2); various places in the Casiano field; Cerros Chapopote and Las Borrachas, near Juan Felipe; Cerros Chapopotal, Palma

FIG. 2.—Sketch map of Mata de Chapopote seepage and of line of seepages in Chila Salinas pool, Pánuco arch. Production on this and other maps is not up to date.

Real, and Calcalote, near Potrero del Llano; Cerro Pelon, near Solis, Tierra Amarilla; Cerro Apachiltepec in southern Tlacolula; and Cerro Chapopote north of the Alamo field.

At all of these places, seepages are found at or near the zone of contact. Some of the seepages occur within the area of igneous rock, but apparently such position is caused by fissures in the rock itself.

At Mata de Chapopote (Fig. 2) and Cerro Pelon (Fig. 3), the occurrences of seepages along straight lines suggest buried dikes or faults. This line at Mata de Chapopote is not sharply defined. Seepages occur in a north-south striking zone about 1½ miles long, the center of the zone lying just east of the outcrop of igneous rock. At Cerro Pelon a

clearly defined line of seepages extends from the base of the hill southeast into the hacienda Tierra Amarilla for a distance of 1¼ miles.

Seepages along dikes are also of common occurrence, notable examples being at Chapopote in the hacienda San José de las Rusias, Tamaulipas, where asphalt exudes along the contact of a basalt dike with baked marls; at Lavaderos, in the same hacienda where asphalt issues from weathered joints in a small boss of dolerite, and in the western part of the hacienda where asphalt seeps from joints in a large boss of syenite; at Tampalache, in the Pánuco field; in the haciendas of San Geronimo and San Antonio y Tamijui, canton of Ozuluama; in lots

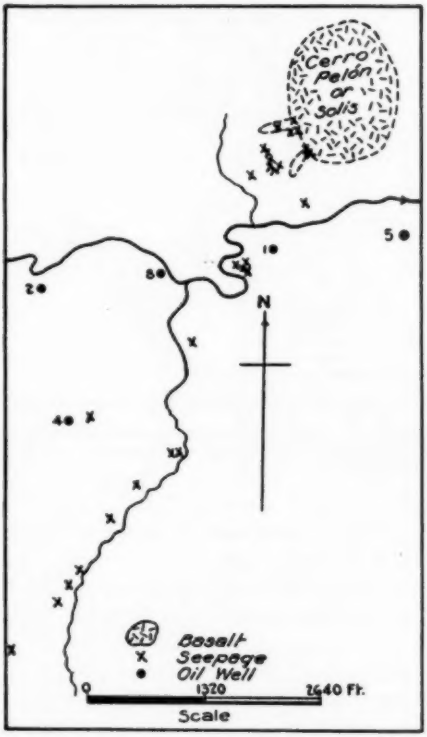

FIG. 3.—Map of seepages near Cerro Pelon or Solis, Tierra Amarilla, aligned so as to suggest a fault or dike.

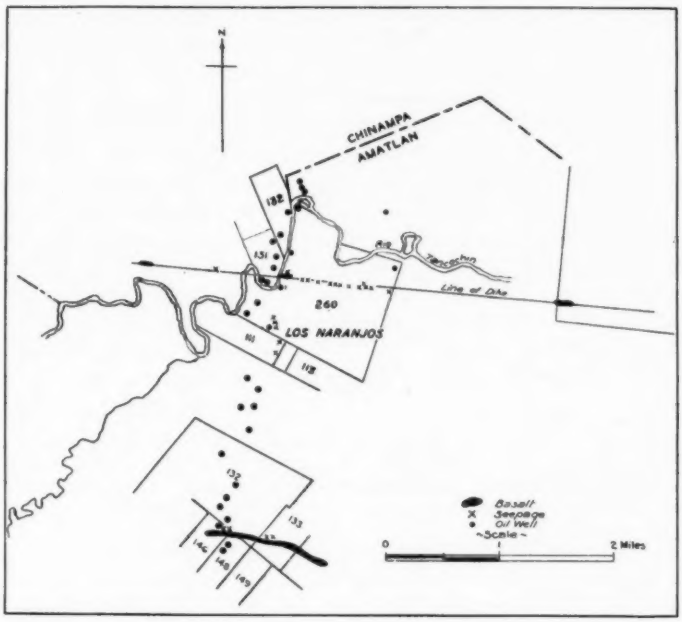

FIG. 4.—Map of basalt dikes and seepages in Los Naranjos field.

260 and 133, Amatlan, Los Naranjos field (Fig. 4); Acala; and in the northwestern part of the hacienda Tlacolula.

In most of these examples the seepage occurs at the wall of the dike. At Tamalache, Pánuco district, the dike does not crop out but was encountered in drilling. Oil is also reported to have been found in vesicles in basalt about the depth of 3,700 feet in the Corona well No. 82 at San Manuel, Pánuco. Showings of oil were noted where this rock made contact with upper Jurassic sediments into which it was intruded.

At San Antonio y Tamijui, seepages occur at intervals along a direct line about 1½ miles in length (Fig. 5); outcrops of the dike being found near each end of the line. In lot 260, Amatlan, Los Naranjos field (Fig. 4), seepages occur along a very sharply defined line 1¼ miles in length, along the eastward projection of which, and about 1½ miles beyond the last seepage, is an outcrop of basalt. At the west end of the

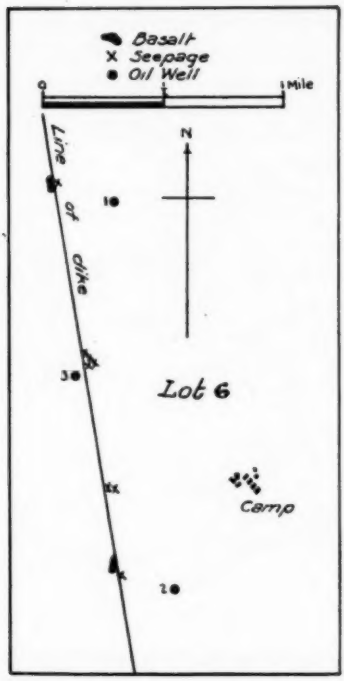

FIG. 5.—Map of seepages at San Antonio y Tamijui, southeast of Ozuluama. Seepages arise along a basalt dike which crops out in two places.

line of seepages a basalt dike occurs on the east bank of the River Tancochin, but is now covered by alluvium.

Large seepages are found in the haciendas of Aguada and Comales in the vicinity of igneous intrusions. In a well drilled by the Cortez Oil Corporation a core of holocrystalline igneous rock from a depth of 3,980 feet showed oil in vesicles in the rock. This well is located close to the west side of the basaltic plug Cerro Taninul illustrated by Huntley.[1] Seepages occur at the surface close to the plug.

The Mexican Fuel Company (Pierce Oil Corporation) produced approximately 6,800 barrels of 32° Bé. oil from a coarse, glassy volcanic tuff in their Cerritos wells No. 1 and No. 3 in the Topila field. The

[1]L. G. Huntley, "The Mexican Oil Fields," *Trans. Amer. Inst. Min. Eng.*, Vol. 52 (1915).

thickness of the tuff was about 5 feet and it was encountered at a depth of 2,040 feet at the top of the San Felipe formation, or base of the Mendex.

There are two occurrences of oil in igneous rock in the Tampico-Tuxpam region which are quite different from those already described.

Near the southern boundary of the hacienda Tamemas, canton of Tantoyuca, state of Vera Cruz, is a small outcrop of basalt of unknown form, but either a plug or dike. Near it is a seepage of heavy oil (14°-15° Bé.) of deep brown color and very marked green fluorescense, which is apparently the residue of a much lighter oil similar to that of San Pedro or to the oil found within the basalt of the dike. The basalt of the dike contains numerous vesicles which are lined with chalcedony and many of which contain light green oil (40°-50° Bé.), some of the larger vesicles as much as three or four drops.

Samples of this basalt were examined microscopically by Sidney Paige, who reports as follows.

> Fine-grained olivine basalt, pyroxene only in small grains. Amygdules are filled with calcite in the majority of cases. Some are lined with chalcedonic quartz (opal). Others are lined with opal and filled with calcite. Secondary calcite is noteworthy and is in places pseudomorphic after olivine.

A similar basalt outcrop and seepage of light oil occurs on the northwest side of the Cerro de Tambucan in the southernmost part of the hacienda Tamelul, a few miles north of the Tamemas seepage. The sedimentary rocks on the east, south, and west sides of the hill dip away from it at angles ranging from 25° to 45°, indicating sharp doming and probably a volcanic plug.

It seems probable that the oil included in the basalt was derived by circulating waters from adjacent sedimentary formations after the rock had cooled, though it may have been distilled from the sediments before the basalt had cooled.

EFFECT OF INTRUSIONS ON OIL ACCUMULATION

The foregoing are the common types of the association of oil seepages and igneous rocks in the Tampico-Tuxpam region of Mexico. The area of most common occurrence of igneous intrusives is also the area of the most common occurrence of seepages.

The writer doubts whether volcanic activity in the Tampico-Tuxpam region is a factor of any importance in the occurrence or production of oil beyond the facts that it provided channels along which oil rises to the surface, thus forming seepages, and, being of comparatively recent

geologic age, furnished the heat which is so characteristic of the oils and oil-field waters of the region. Heat reduces viscosity, and heat of volcanic origin may have been an important factor in facilitating the migration and accumulation of oil. It is certainly of considerable importance in facilitating the production of such heavy and viscous oils as those of the Pánuco and Ebano fields.

FURBERO OIL FIELD

The most notable occurrence of oil in association with igneous rocks which has yet been found in Mexico, however, is that in the Furbero oil field, canton of Papantla, state of Vera Cruz (Fig. 6).

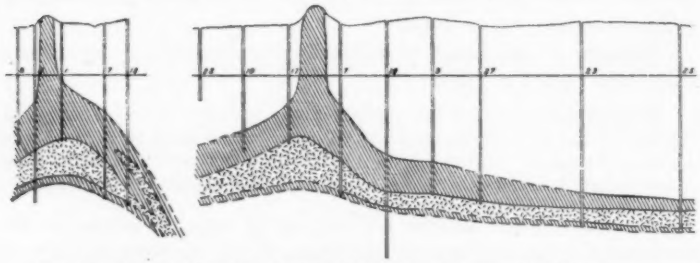

FIG. 6.—Cross sections of Furbero oil field. Well No. 7, near pipe of metamorphosed shale, is common to both cross sections. Left-hand section is southwest-northeast and length between outside wells shown is 1,500 feet. Other section is northwest-southeast and length is 9,800 feet. Depth of well No. 11 (between wells 8 and 1 in left-hand section) is 2,350 feet. Gabbro in this well was 363 feet thick (1,665 - 2,028 feet) with good showing of oil at upper contact. Well No. 27, which has yielded nearly half production of field, had initial production of 1,000 barrels daily with penetration of 30 feet in gabbro. (From *Trans. Amer. Inst. Min. Eng.*, Vol. 52, p. 272.)

At this place, a thick sill of igneous rock has been intruded into the Tertiary shales. The sill is somewhat folded, probably following bedding planes in the previously folded shale. Metamorphism of the contiguous shales has occurred, to depths ranging from 50 to 100 feet for the underlying shales, and for thicknesses ranging from 100 to 500 feet for the overlying shales, excepting a pipe of metamorphosed rock which continues to the surface, where it forms two sharp hills somewhat resembling volcanic plugs.[1]

[1]For plan of the field and sections see: E. DeGolyer, "The Furbero Oil Field, Mexico," *op. cit.*

A sample of the igneous rock from Furbero well No. 13 has been examined microscopically by Sidney Paige, who reports as follows.

> Furbero well No. 13. Gabbro, medium grained. Pyroxene, brown hornblende, and a little biotite. Feldspar basic. Secondary: chlorite, sericite (in sheaths) and chalcedonic quartz. Chlorite after ferromagnesian minerals. Feldspars altering to dull opaque material with formation of secondary silica and sericite. Processes of alteration are quite advanced. The white specks showing in the hand specimen are a combination of sericite and secondary silica.

It is interesting to note that, in the early development of the field, this material was usually pounded into a gray sand by cable-tool bits, and that for a long time even the geologists failed to recognize the igneous origin of this structure, but mistook it for a simple anticline with a thick body of exceptionally clean sand.

The oil in this field, which has produced 1,971,600 barrels to the end of 1931 and which is now producing 183 barrels a day from 8 wells, is found in the igneous rocks and in the metamorphosed shales, chiefly near the contact of the igneous mass with the overlying shales. Well No. 27, at 30 feet into the igneous rock, came in with an initial production of 893 barrels, and had produced 200,000 barrels to the early part of 1914, when it was still good for a flow of 490 barrels. The production at the close of 1931 was 61 barrels a day, and the total production was 774,300 barrels. Well No. 28 had an initial production of 100 barrels from 157 feet into the igneous mass, and only 9 feet above its base. Well No. 9 produced approximately 170,000 barrels from the upper metamorphosed shales.

The writer sees no particular significance in this exceptional association of oil and igneous rock beyond the fact that the intrusion of the igneous rock from below and its metamorphism of contiguous shales formed a channel for migration from deeply buried oil-bearing beds and a trap for the accumulation of the oil.

OCCURRENCES OUTSIDE KNOWN OIL REGIONS

Small amounts of light oil have been secured from springs and from prospect wells drilled near Guadalupe in the volcanic rocks of the valley in Mexico.

Seepages of light oil are found near Pochutla and Puerto Angel, state of Oaxaca, near the Pacific Ocean, in a region of gneiss, schist, limestone (probably metamorphosed), and granite.

Seepages of heavy oil are reported as occurring in volcanic rocks at Lake Chapala and vicinity in the states of Jalisco and Michoacan. The oil bubbles up on Lake Chapala.

Heavy, viscous oil is also reported as occurring in the crevices and flow places of the basalt cap of a mesa near the ranch of Chicuasi, Canton Jalapa, Vera Cruz.

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VOL. 16, NO. 8 (AUGUST, 1932), PP. 809-818, 1 FIG.

OCCURRENCE OF OIL IN IGNEOUS ROCKS OF CUBA[1]

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ABSTRACT

The seepages of oil, the asphalt deposits, and the two oil fields, Bacuranao and Motembo, are described with special reference to the association of oil and asphalt with igneous rocks. Production in both oil fields is from serpentine and no commercial production has been found in sedimentary rocks. It is estimated that more than 200,000,000 barrels of asphaltic oil was required to form the asphalt deposits and seepages.

SUMMARY

A great number of seepages of oil and many commercial deposits of asphalt occur in Cuba. Part of them are associated with serpentine and ferromagnesian igneous rocks. One commercial oil field, Bacuranao, and one semi-commercial naphtha field, Motembo, have been developed in serpentine. In spite of the abundance of residual oil, exploration has failed thus far to find commercial oil in normally bedded sands in the sedimentary rocks. The geology of Cuba has been described in a separate article by the writer,[3] and the petroleum geology by DeGolyer.[4] Many of the data have been taken from the latter publication. The writer acknowledges receipt of assistance from several friends who were studying the geology of Cuba at the time of his investigation.

IGNEOUS ROCKS

Hundreds of seepages of oil and gas are found in central and western Cuba. Several asphalt deposits have been mined and two are still being mined. Most of the surface occurrences of petroleum are found within or close to areas of serpentine or ferromagnesian igneous rocks which probably have the form of plugs, dikes, denuded laccoliths, and possibly

[1]Manuscript received, January, 1932.

[2]Consulting geologist, 5823 Monticello Avenue.

[3]J. Whitney Lewis, "Geology of Cuba," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 6 (June, 1932), pp. 533-55.

[4]E. DeGolyer, "The Geology of Cuban Petroleum Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), pp. 133-66.

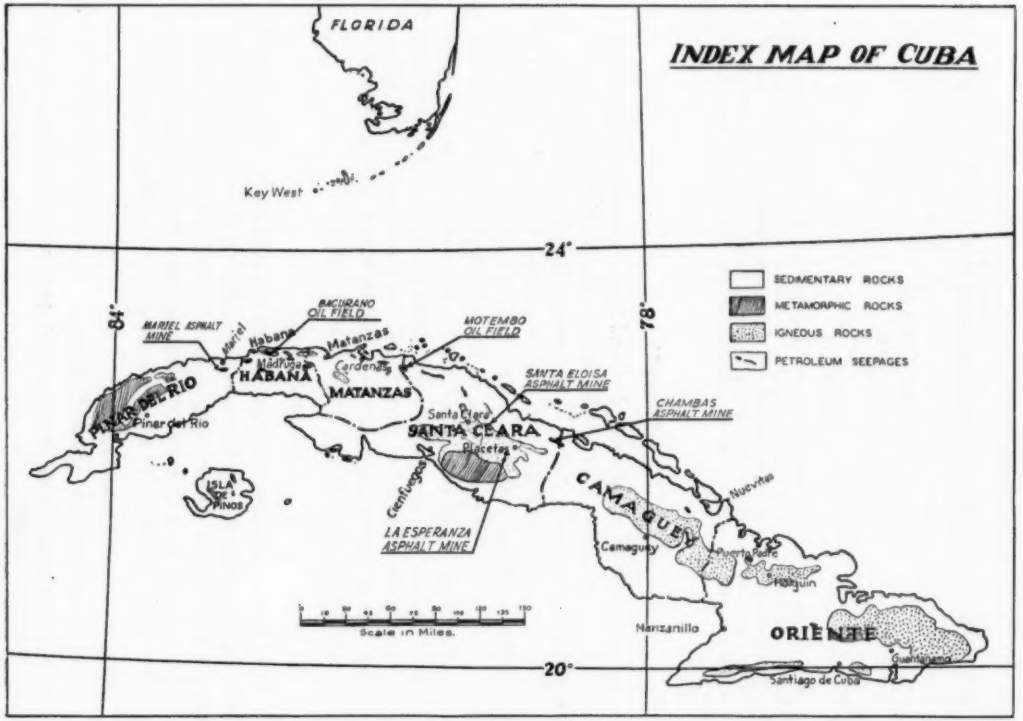

FIG. 1.—Map of Cuba, showing oil seepages, oil fields, most important asphalt mines, and generalized geology.

lava flows. The intrusive rocks have penetrated or partly covered sedimentary rocks.

Granitic rocks and serpentines are found in the Basement complex. These, and the serpentines in the sedimentary rocks, have been cut by younger dikes. A diorite (?) dike cuts serpentine east of Habana and oil seeps to the surface along the walls of the dike and through crevices in it. Other dikes are known on the island. "Obsidian," which is probably an olivinitic rock, was encountered in wells drilled at Motembo.[1]

GEOLOGIC HISTORY

The writer has described the geology of Cuba in a separate article[2] and only a very brief summary is given here. The Basement complex consists of granite rocks, metamorphosed schist, shale, and marble. This is overlain by the Vinales limestone, of Jurassic age, consisting of 1,500 feet or more of highly bituminous limestone and shale. Unconformably on the Vinales, basal conglomerates, bituminous sands, and shales of Cretaceous age crop out on the flanks of the mountain areas. Within the Cretaceous there is one unconformity. Eocene limestones, marls, and shales are separated by a major unconformity from the older rocks. Cavernous Miocene limestones rest unconformably on Eocene rocks. In general, structure in the Tertiary rocks reflects that in the older rocks.

Intrusions of ferromagnesian igneous rock are of several ages. Fragments of Jurassic and Cretaceous limestones have been found in serpentine near Cardenas, yet arkose and conglomerate of Lower Cretaceous age in Santa Clara Province contain serpentine pebbles.[3] Also, as previously stated, dikes are known to cut serpentine. Therefore, some of the igneous rocks must be of pre-Cretaceous age and must have been serpentinized in pre-Cretaceous time; other igneous rocks must be post-Lower Cretaceous and are probably of post-Eocene age.

The source rock of petroleum is believed to be either Jurassic limestone or Cretaceous shale, or possibly both. Cretaceous sands are considered to be the most probable sedimentary reservoir rocks, although they have not yet been proved to contain oil. In most places these sands are believed to lie within 4,000 feet of the surface.

STRUCTURE

The general structure of the island is asymmetrically anticlinal with several systems of folding superposed. The older igneous, metamorphic, and sedimentary rocks are complexly and steeply folded and deeply

[1] E. DeGolyer, *op. cit.*

[2] J. Whitney Lewis, *op. cit.*

[3] E. DeGolyer, *op. cit.*, p. 138.

truncated where exposed in the central part of the island. The Cretaceous and older rocks are cut by many intrusions of diorite and ferromagnesian rocks, most of which are serpentinized. The final uplift of the island must have taken place in late Tertiary or post-Tertiary time.

Much more exploration will be required to prove or condemn the oil possibilities of Cuba.

SEEPAGES

Surface manifestations of petroleum are live seepages that vary from gas to colorless naphtha, light oil, and heavy oil. Extinct seepages are asphalt and gilsonite. Seepages may be individual or in groups. Asphalt and gilsonite deposits are frequently of large size, as described later in this paper.

Most oil and gas seepages are related to fissures or systems of fissures. Some of the fissures which cut or abut igneous rocks are believed to have developed during the intrusion and subsequent hydration of these rocks. In some places oil has migrated and accumulated along the fissures and in the adjacent igneous and sedimentary rocks.

The fissures are believed to be Eocene or post-Eocene because in several places the intrusions cut the Eocene rocks. Most of the asphalt deposits observed in mines are laminated horizontally with little or no indication of vertical flow structure; hence they have not been compressed since formation.

The seepages actually associated with intrusive rocks must have commenced with and continued during the intrusion, hydration, and cooling. It seems probable that most of them became inactive either because of the exhaustion of the source supply or the sealing of the outlets by residuums. This probably took place within a few years after the cooling of the intrusions. Recurrent minor deformations of the island appear to have caused repeated rejuvenations of many of the sealed seepages and to be responsible for those that are active to-day. In the cases of asphalt and gilsonite deposits which occupy large tension fissures the purity of the material and the dimensions of the fissures indicate that they were probably formed very rapidly, for the most part within a few years after the formation of the fissures. More than 30,000,000 barrels of heavy asphaltic oil such as Panuco crude, or, in other words, an amount equal to that in a fair-sized oil field, must have evaporated and oxidized to form a single deposit, like Mariel, containing more than 2,000,000 tons (10,000,000 barrels) of gilsonite.[1]

[1] It has been estimated that 20,000,000 to 30,000,000 barrels of oil must have been oxidized to leave this residue (Albert Wright, Jr., and P. W. K. Sweet, "The Jurassic as a Source of Oil in Western Cuba," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 4 (July-August, 1924), pp. 516-19). The present known reserves of this deposit are at least three times what they were when the foregoing estimate was made.

Other smaller asphalt deposits represent the draining of additional millions of barrels of oil. The light oil which is now produced may be the volatile part of either relic oil fields, or only partly depleted pools.

Description of the better known petroleum occurrences in both igneous and sedimentary rocks are given by DeGolyer[1] and little more has been learned concerning them since his visit in 1915. Official bulletins[2] give descriptions of the more important of the 30 or more asphalt deposits which have been exploited. Therefore, only the most important and typical asphalt deposits are described here, the Mariel mine being in sedimentary rocks.

FAVORABLE RESULTS OF EXPLORATION[3]

During 1881, in the first well drilled for oil in Cuba, located close to gas seepages, natural naphtha was found at the site of the present Motembo oil field. Several wells were drilled in 1890-96 in the Lagunillas district west of Cardenas and one well produced some oil. In 1913 a considerable flow of gas was encountered at Puentas Grandes in the western part of the city of Habana at a depth of 60 feet. The Bacuranao field 10 miles east of Habana was discovered in 1915. Other significant showings of oil and gas in wells besides those mentioned have been found at the following localities: oil on the Alvarez properties 6 miles west of Cardenas; oil and gas in the Williams well at Guayabal, 25 miles west of Habana; oil in the Cuban Petroleum Company well No. 1, 4 miles west of Santa Clara in serpentine; and gas in a well drilled near seepages from fissures at Bejucal, 19 miles south of Habana. Of these all but the Guayabal well started near or in known serpentine.

OIL FIELDS

Motembo oil field.—This field is on the line between Santa Clara and Matanzas Provinces 34 miles east of Cardenas. It is situated on a rounded highland which is approximately 3 miles in diameter and rises 325 feet above the flat coastal plain. This highland is composed of serpentine which is cut by numerous secondary intrusions of "obsidian" (probably olivinitic rock) and in which cracks and small fissures are numerous. The surrounding area is covered with maroon clay marls and alluvium much of which is capped with a thin mantle of hematite pebbles. A hematite gossan, in many places having a thickness of 4 feet, covers the serpentine. There are few if any exposures in the flats that indicate

[1]E. DeGolyer, *op. cit.*, pp. 148-57. See also, H. C. Brown, "Mineral Resources of Cuba in 1901," in *Civil Report of Military Governor, Brig. Gen. Leonard Wood, 1902*, Vol. 5, Pt. 2.

[2]*Direcciõn de Montes y Mines, Republica de Cuba Boletin 13, 14* (Habana, 1928-1929).

[3]Summarized from E. DeGolyer, *op. cit.*

the nature and structure of the underlying formations. Small quantities of inflammable gas seep from cracks in the serpentine at several places within an area of 6 acres and the wells that have been drilled to date are located close to them. The hematite is spoken of locally as "volcanic cinders" and a sink hole in this material near the wells is called "the volcano" (both terms being misnomers). The serpentine appears to be an intrusion situated on the faulted crest of an east-west trending anticline. In all probability the serpentine has moved upward through a fissure and spread in mushroom fashion on approaching the surface and then been denuded by erosion.

In 1881, in the discovery well, 26 gallons per day of colorless naphtha was encountered at 285 feet, and there were several other deeper showings. The total depth of this well was 1,000 feet. Five other wells were drilled to depths of 950, 800, 400, 700, and 1,905 feet respectively.[1] The logs of these wells were similar: diorite to 85 feet, altered diorite (?) and "obsidian" 85 to 142 feet, altered serpentine (?) and "obsidian" 142 to 173 feet, serpentine to the bottom of the hole. Of these five the first and second had insignificant showings of naphtha. The third developed production, but was lost through a fishing job. The last produced at the rate of 4-5 barrels of 56° Bé. gravity oil per day for some time. The total production has been about 5,000 barrels. Recently one well has been cleaned out with the view of deepening it and the operators state that it is now flowing at the initial rate, and has filled all available storage. The naphtha production is accompanied by appreciable quantities of inflammable gas.

An analysis of the naphtha from the Cuban-American Oil Company No. 3, has been published. The analysts consider the naphtha to be a fractionation product derived from the filtration of heavy petroleum through clay which acted like fuller's earth.[2]

Naphtha, very pale yellow color, from a mixture of 72 per cent oil, 28 per cent water depth, 1,560 feet.

Sp. gr. 0.732 N_D 25° 1.4092

		Engler Distillation		
Temperature	*Per Cent Weight*	*Sp. gr. 15.6°*	*Sp. gr. 20°/20°*	N_D 25°
75°	3.5			1.3900
75°-100°	18.9	0.72		1.4002
100°-125°	51.3	0.739	0.7372	1.4094
125°-150°	18.4	0.75	0.7497	1.4166
150°-160°	1.2			1.4242
Residue	2.1			1.4492

[1]Subsequent information is that seven more wells have been drilled and that present production comes from one of them.

[2]C. Richardson and K. G. MacKenzie, "A Natural Naphtha from the Province of Santa Clara, Cuba," *Amer. Jour. Sci., Ser. 5*, Vol. 29 (1910), pp. 439-46.

An analysis of naphtha which seeps from Sandalwood Spring, Santa Clara Province, and which is used as an illuminating oil without refining is as follows.[1]

Sample 2 liters, oil and water; sp. gr. oil at 33/33 0.901.

Fractions

Under	250°	3.3	290-300	18.0
	250-260	6.0	300-300	8.4
	260-270	11.2	310-330	13.1
	270-280	12.1	Residue	11.3
	280-290	16.6		

Hard, dried oil contains 86.9 per cent *C.*, 12.7 per cent *H.*, 0.6 per cent *O.*, *N.*, et cetera.

Higher paraffines absent.

Bacuranao oil field.—This field is 10 miles east of Habana. Since the discovery of the field in 1915, about 40 wells have been drilled within an area of less than 160 acres. They are owned by the Union Oil Company, a local concern.

The field is situated on the north edge of a serpentine mass which is approximately 3½ miles in diameter. The serpentine at the outcrop is fractured and recemented with calcium carbonate. The solid rock contains globules of oil. Just north of the field are limestones and marls of Tertiary age which dip regionally northward, though there are a few local dips toward the serpentine. One interpretation of structure places a fault between the limestone and the serpentine. A small mass of older rock (Cretaceous ?), found in the middle of the oil field, may be a large inclusion in the serpentine.

The wells were located because of light-oil seepages which have since been obliterated by drilling operations. The production is generally encountered at a depth between 200 and 800 feet in fissures in the serpentine. The initial flows range from 25 to 200 barrels per day with a very rapid decline to 10 barrels. In January, 1930, a well was completed at 713 feet which filled a 1,250-barrel tank in 36 hours. This well was near the north edge of the field. The gravity of the oil was 28° Bé. whereas that of the oil from the other wells was 34° Bé. The field is making approximately 30 barrels per day at the present time. Salt water has been encountered in several wells.

An analysis of the oil is as follows.[2]

[1]N. H. Stokes, "On Petroleum from Cuba," *U. S. Geol. Survey Bull. 78* (1891), pp. 98-104.

[2]*Rep. de Cuba Boletin de Minas Num. 13*, p. 70.

BACURANAO FIELD—DECEMBER, 1926

Density at 15° C.	.8845
Density at 25° C.	.8908
Flash point	20° to 22° C.

Distillation	*Per Cent*		*Specific Gravity*
80° to 150° C.	13	Gasoline and benzene	0.7345
150° to 300° C.	31	Illuminating oil	0.8162
300° to 400° C.	41	Lubricating oil	0.898

These oils contain much paraffine which solidifies completely upon refrigeration. The residue (from distillation) is 12.4 per cent. This contains paraffine asphalt, carbon, and 0.5 per cent mineral matter.

The production by years has been as follows.

OIL PRODUCED IN CUBA*

Year	*Barrels*	*Year*	*Barrels*
1916	113†	1924	3,877†
1917	20,386†	1925	3,501†
1918	23,108†	1926	2,000‡
1919	9,226†	1927	3,000‡
1920	10,278†	1928	4,527‖
1921	5,365†	1929	1,952‖
1922	4,063†	1930	7,006‖
1923	3,307†	1931	11,209‖
		Total	112,918

*These figures were very kindly furnished by Frederick G. Clapp. See A. H. Redfield, Report III, Federal Oil Conservation Board, Washington, 1929.
†*Republica de Cuba Boletin de Minas 13* (Habana, 1929).
‡*Mineral Resources of United States.*
‖American consul at Habana.

ASPHALT MINES

Santa Eloisa.—This mine is 8 miles east of Santa Clara. The asphalt occurs as a northwest-striking vertical vein in serpentine. It averages 10 feet in thickness, has been exploited to a depth of 130 feet and drifted 325 feet without defining the limits of the deposit. The asphalt is brilliant to lusterless. It has a strong petroleum odor and melts easily. More than 500 tons have been mined, most of which was used as a gas enricher in Santa Clara. The mine was abandoned and flooded. There are several other similar, but undeveloped, deposits in the vicinity.

La Esperanza.—This asphalt deposit is 5 miles southwest of Placetas, Santa Clara Province. The country rock is serpentine. The main deposit occupies a fissure which extends N. 60° W. and dips 80° S. The mine is being operated by the Mariel Asphalt Company, and its manager, Sr. Guillermo Prieto, states that the main shaft is 308 feet deep and

that the 260-foot level has been drifted more than 2,000 feet. The average width of the vein at this depth is 25 feet. No attempt has been made to measure the reserve. The asphalt is a high grade grahamite averaging 98 per cent pure. Enough gas is present in the workings to require the use of safety lamps. During the early part of 1931, 300 tons per month were shipped to the United States for the paint and varnish industry.

Chambas.—This mine is in the northern portion of Santa Clara Province, near the eastern boundary. The deposit occurs in serpentine about 650 feet south of its contact with limestone of Cretaceous (?) age which has been metamorphosed by the intrusion (?). There are several veins of asphalt in this vicinity. The one which is being mined strikes N. 30° E. and the workings have proved the deposit to be at least 1,000 feet long and 560 feet deep, with an average width of 4 feet. About 30 tons per day were being mined in 1931 and it is estimated that 5,000 tons have been mined to date. A 40,000-ton reserve is proved. The material is brilliant grahamite which has a strong petroleum odor. Maltha oozes from the walls of the workings in appreciable quantities. This description is taken from Boletín de Minas, No. 13.

Madruga seepage.—A typical example of the occurrence of petroleum in serpentine is located a short distance north of Madruga in the eastern portion of Habana Province. The serpentine plug is approximately 2 miles long from east to west and ¼ mile wide. This intrusion lies slightly north of the axis of the Madruga-Guines-Bejucal anticline. Miocene rocks crop out north of the intrusion and Cretaceous rocks south of it. The Central Highway cuts an excellent section through the south flank of the anticline.

Within the serpentine there are many outcropping fragments of dark blue metamorphosed limestone saturated with petroleum. It is stated that light oil seeped out of the serpentine during the excavation for the highway. Within the serpentine area at a point ½ mile east of the town a pit dug in black limestone is partly filled with maltha. The limestone is probably of Jurassic (possibly Cretaceous) age and appears to have been carried upward from a great depth by the serpentine.

A short distance east of Madruga a well was drilled on the axis of the Madruga anticline to a depth of 2,400 feet and, according to reports, had showings of oil and gas in the Upper Cretaceous. However, it did not reach the depths at which the Cretaceous basal conglomerates and sands could reasonably be expected.

Mariel.—Six miles south of the port of Mariel, in Pinar del Rio Province, there is a group of six gilsonite veins. These trend approx-

imately N. 70° E. and incline slightly north. They cut Cretaceous shales, sands, and limestones. Much of the region is soil-covered and in cultivation and there are not sufficient exposures to determine the areal geology in a hurried reconnaissance. The outcrops of most of these veins have been quarried and in the case of the largest, a shaft was sunk to 400 feet and drifts and stopes developed at each 100-foot level. These workings have proved the deposits to be more than 1,400 feet long and from 10 to 70 feet wide. Core drilling has outlined the deposit to a depth of 800 feet and a length of more than 4,000 feet without defining its limits.

The east parts of the workings are said to have encountered coarse limestone conglomerates. As far as the writer is aware, there are no igneous rocks closely associated with the veins; however, there is a small serpentine plug approximately 1 mile northeast of the mine and it is not improbable that other small intrusions are present in the soil-covered areas near by. The mine was closed at the time of the writer's visit in 1931 because of a fatal gas explosion. At that time the mine superintendent stated that soft asphalt, together with a small quantity of inflammable gas, exuded from the walls of the lower levels. He also stated that between 250,000 and 450,000 tons had been mined prior to December, 1930, and that a reserve of between 3,000,000 and 6,000,000 tons was estimated. The official report[1] states that 200,000 tons have been mined and that 2,400,000 tons are in reserve. These mines are owned by the Oil Trust, Ltd., London.

[1] *Republica de Cuba Boletin de Minas 13* (1929), pp. 67-68.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 8 (AUGUST, 1932), PP. 819-824, 2 FIGS.

OIL SEEPAGES AND OIL PRODUCTION ASSOCIATED WITH VOLCANIC PLUGS IN MENDOZA PROVINCE, ARGENTINA[1]

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ABSTRACT

In the eastern foothills belt of the Andes Mountains, in western Mendoza Province, Argentina, a series of lower Tertiary and older strata has been folded, faulted, and locally intruded by igneous plugs. Seepages of asphaltic oil, and dikes or veins of rafaelite, are found associated with the faults and intrusive masses, in such a way as to indicate that these petroleum substances originated from a shale of Upper Jurassic age, or from limestone of Lower Cretaceous age, or from both. Near one of the igneous plugs, Cerro Alquitran, a considerable quantity of heavy oil has been obtained by drilling.

In western central Mendoza Province, Argentina, in the foothills belt of the Andes, is exposed a highly folded and faulted series of strata ranging in age from Lower Jurassic to middle Tertiary.[3] These strata rest unconformably, and with overlapping sequence, on an older basement. The lower Eocene and older formations have been intruded by dikes and plugs of andesite, which apparently broke out at the surface, for unconformably above the lower Eocene are thick agglomerates of middle Tertiary age, which contain a great deal of similar andesitic detrital matter. The best known of these plugs are Cerro Alquitran, North Cerro de los Buitres, South Cerro de los Buitres, Cerro de la Laguna Seca, Cerro de la Brea, and Cerro de la Mala Dormida (Fig. 1). Three of them occur on a ranch known as El Sosneado. They seem to be truncated volcanic necks.

The Jurassic sequence contains at the top a thick formation of dark gray to black, rather soft shale, which has been previously described as the "Ammonite shale."[4]

[1]Manuscript received, June 26, 1931.

[2]Chief geologist, Sun Oil Company.

[3]For descriptions of the formations in this region see Pablo Groeber, "Estratigrafía del Dogger en la República Argentina," *Dirección General de Minas, Geología e Hidrología, Boletín 18*, Serie B, Geología (Buenos Aires, 1918); also Enrique Gerth, "Contribuciones a la Estratigrafía y Paleontología de los Andes Argentinos," *Actas de la Academia Nacional de Ciencias de la República Argentina*, Tomo ix, pag. 1, y sig. 1925.

[4]F. H. Lahee, "Petroliferous Belt of Central-Western Mendoza Province, Argentina," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 3 (March, 1927), pp. 261-78; "Note on the Origin of Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (September-October, 1924), pp. 669-71.

It contains many pelecypods and cephalopods of Portlandian affinity, and in many places rounded limy concretions.... Chips of the Ammonite shale, when placed in ether or chloroform, gradually yield enough oil to discolor the fluid. When heated, the rock gives off very strong petroliferous fumes. Quantitative ignition tests demonstrated that fragments of the shale suffered

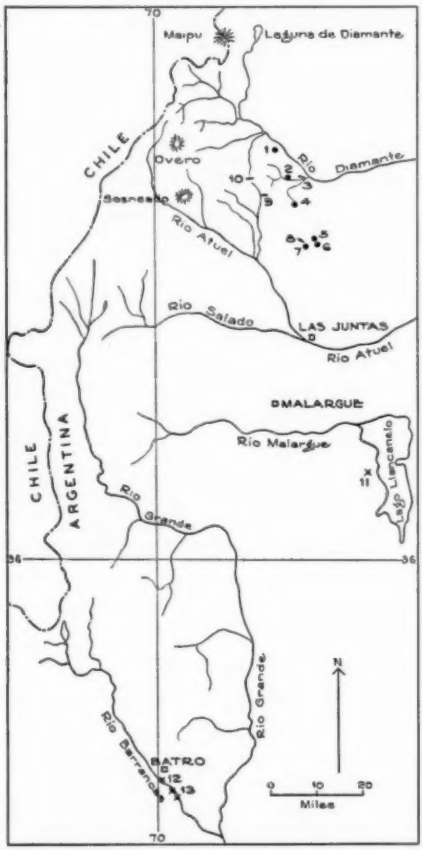

FIG. 1.—Index map of part of western Mendoza Province, Argentina, showing positions of certain asphalt seepages, rafaelite veins, and andesite plugs. *1*, Cerro de la Mala Dormida; *2*, Cerro de la Brea; *3*, Diamante asphalt seepage; *4*, Cerro de la Laguna Seca; *5*, North Cerro de los Buitres; *6*, South Cerro de los Buitres; *7*, Cerro Alquitran; *8*, Paloma asphalt seepage; *9* and *10*, veins of rafaelite; *11*, Llancanelo asphalt seepage; *12* and *13*, Batro asphalt seepages.

a loss of 18 per cent by weight, this loss probably being chiefly petroliferous material. Fresh fractures of the shale exhibit an oily iridescence, and the cephalopods, when broken open, may show a solid petroleum residue of grahamite or rafaelite.[1] This is interesting, for it indicates, since the Ammonite shale contains no observed plant remains, but instead a profusion of animal remains, that the petroliferous matter had its source in these animal remains.[2]

This shale formation varies in thickness from 400 to 900 feet.

The sedimentary formations shown in Table I conformably overlie the Ammonite shale.

TABLE I

SEDIMENTARY FORMATIONS OVERLYING AMMONITE SHALE

Post-Tertiary	Recent	Alluvium, wind-blown sands, plains gravels, valley gravels, valley tuffs, and glacial deposits
Tertiary	Ranch-house conglomerate	6,000 feet or more thick, consisting of basal reddish sandy and conglomeratic member; middle gray conglomeratic member; and upper coarse gray volcanic agglomerate
	Probable unconformity	
Eocene or uppermost Cretaceous (Danian)	Ramadas series	2,000-3,500 feet thick. Consisting of upper and lower members of non-fossiliferous variegated shales and sandstones partly gypsiferous; and middle member containing highly fossiliferous sandy limestone beds
Cretaceous	Salas sandstone series	Non-fossiliferous, 1,000-1,800 feet thick
	Salas limestone series	Including lower shale member overlain by upper member containing cherty, non-fossiliferous limestones, and some gypsum and shale. 130-200 feet thick
Lower Cretaceous (Neocomian)	Diamante limestone	Massive, white, fossiliferous limestone, 40-800 feet thick

Outcropping strata ranging in age from the Salas group to the lowest part of the Ranch-house conglomerate[3] may be seen tilted at high angles against the andesite plugs.

[1] *Op. cit.* (1924).

[2] *Op. cit.* (1927), pp. 269-70. This shale has also been described by Enrique Gerth, *op. cit.*, pp. 37-42.

[3] Communication from Kenneth Aid and A. J. Bauernschmidt.

Extinct seepages in the form of veins of rafaelite,[1] and live seepages of black tarry oil, are plentiful in the foothills belt from Diamante River southward at least as far as Batro, on Rio Barrancas about 16 miles above its junction with Rio Grande, in extreme southern Mendoza Province (Fig. 1).[2] Practically all these seepages are clearly located along faults or are in association with the andesite intrusions. In the latter case the oil escapes from fractures or from the exposed edges of strata sharply upturned against the plugs. Possibly some of the oil may ascend along the actual contact, but this could not be proved in the localities known to the writer.

Cerro Alquitran (Fig. 2), as the most conspicuous and the most extensively explored of the several plugs, merits description here. This hill, consisting of a massive gray andesite containing abundant phenocrysts of plagioclase and hornblende, rises about 250 feet above the surrounding land, which is underlain by strata of uppermost Cretaceous and lower Tertiary age (Ramadas and lower Ranch-house). These beds dip steeply away from the plug. Four seepages of heavy oil flank the hill. Three of these are situated just below the edge of the exposed andesite (Fig. 2). The fourth, consisting of water and a little oil, escapes from a breccia zone well within the mass of the andesite.

With these indications of petroleum as an incentive, beginning as early as 1912 or 1913, and continuing at irregular intervals until 1928, several wells were drilled for oil. At least thirteen were drilled near the plug. Seven or eight of these, all within 700 feet of the andesite, and on the north and west sides, produced oil. Two flowed for several years, although the amount coming out was only a few barrels per day. All the producing wells were drilled to depths between 375 feet and 2,100 feet, that is, none was deep. Apparently in many wells the oil was encountered just below lateral tongues of andesite, either dikes or sills

[1]The following quotation is of interest with reference to these veins of rafaelite: "One of the characteristics of the asphaltites discovered in the Argentine Republic is the presence in all of them of important quantities of vanadium, and a new proof of their petroliferous origin is the fact that the petroleum of the region where the veins of asphaltite outcrop likewise contains V_2O_5. As an example we cite the asphaltite from San Rafael, the ash of which, according to Kyle, contains 38.22 per cent of vanadium anhydrite (V_2O_5), and in the ash from the petroleum from San Rafael Longobardi and Camus report 11.93 per cent of vanadium anhydrite." Translated from Hector Alvarez, "Combustibles Sólidos de la República Argentina," *Actas y Trabajos del Primer Congreso Nacional de Quimica*, Vol. 4, Section tecnica (Buenos Aires, 1921), p. 60.

[2]Kenneth Aid and A. J. Bauernschmidt, "Geology of Southwestern Mendoza Province, Argentina," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 7 (July, 1928), pp. 693-704.

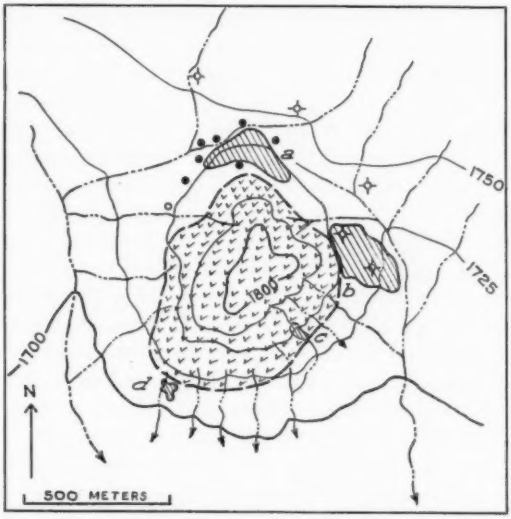

FIG. 2.—Map of Cerro Alquitran showing asphalt seepages (*a*, *b*, *c*, and *d*, lined areas), areal extent of andesite (V pattern), and producing wells and dry holes drilled for oil. Topographic contour interval, 25 meters. (After K. Aid and A. J. Bauernschmidt.)

which projected out from the main plug and thus sealed the upturned edges of the flanking strata. During 1927 and 1928 the total daily production of seven wells was stated to have been about 600 barrels.

The oil is black, viscous, of asphaltic base, and has a gravity of 13° Bé. The following analysis was furnished.

Point of ignition	75° C.
Boiling point	100° C.
Density	.970
Calorific value	12,780 calories

				Density	*Per Cent*
1st	fraction from 107° C.	to	160° C.	.832	10.8
2nd	fraction from 160	to	220	.872	10.0
3rd	fraction from 220	to	265	.880	10.0
4th	fraction from 265	to	270	.882	10.0
5th	fraction from 270	to	274	.883	10.0
6th	fraction from 274	to	278	.888	10.0
7th	fraction from 278	to	285	.896	14.0
	Water				2.0
	Black and pasty residue				18.0
	Loss in distillation				5.2
					100.0

As regards the origin of the petroleum in this part of western Mendoza Province, as far as the writer is aware, all the observed occurrences of rafaelite, with two known exceptions, all the asphalt seepages, and likewise the oil produced in the wells just described, are located where the Ammonite shale and probably also the Diamante limestone are present at no very great depths. In the two exceptions, the oil, escaping from faults, may have travelled laterally along these faults from localities underlain by these same Upper Jurassic and basal Cretaceous strata. The rafaelite which occurs as veins, representing extinct seepages, is very like the rafaelite within the chambers of the cephalopods so abundant in the Ammonite shale. It is believed, therefore, that the rafaelite, the asphalt, and the oil have been derived from the Ammonite shale or from the Diamante limestone, or from both.

The close association of asphalt seepages and oil with the igneous plug of Cerro Alquitran (and to a less extent a like association with other plugs) suggests that the intrusion may have had some effect in forming the petroleum; but, on the other hand, the occurrence of similar asphalt and rafaelite with faults, far removed from any known igneous body, indicates that intrusive action may not have been a requisite condition for their origin. In 1927 the thought was expressed that possibly

> the mechanical action of faulting, together with some heat due to friction or to depth of burial, or the heat and squeezing and shearing attendant upon the intrusion of the andesite plugs, or perhaps both processes, have functioned in the derivation of the petroleum from its mother-substance in the (Ammonite) shale.[1]

Perhaps the origin of this petroleum may have been more widespread due to the pressures and moderate temperatures accompanying regional compression and diastrophism rather than to pressures and temperatures locally and immediately related to faulting and igneous intrusion. In this case the association of the oil with the plugs and the faults would be due merely to the fact that these geologic structures provided avenues for migration. In any event, we believe that there is no reason for postulating an igneous source for the petroleum.

[1] Lahee, *op. cit.*, pp. 277-78.

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OIL IN LIMAGNE AREA, FRANCE[1]

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ABSTRACT

Numerous seepages and showings of oil in wells have encouraged prospecting in the Limagne graben near Clermont-Ferrand near the Volcanic Chain of the Puys. The seepages are most numerous in rock of an exceptional type, called pépérite, which is a form of agglomerate of sedimentary rocks in eruptive rocks. The rôle of volcanic intrusions appears to have been destructive, rather than constructive, and to have distilled away the lighter hydrocarbons.

GEOLOGICAL CHARACTERISTICS OF LIMAGNE

The Limagne is a plain, 18-25 miles wide, drained by Allier River and stretching in a meridian line between the Forez and the Livradois Hills on the east and the plateau bearing the Chain of the Puys on the west. From a geological point of view, this plain corresponds with a sunken Oligocene syncline, oriented north-south, which cuts across the northern part of the crystalline Massif Central.

The deposits filling this syncline show a thickness ranging from 3,300 to 5,000 feet in the axial zone, and their stratigraphic succession is as follows, the oldest being at the bottom.

5. Aquitanian limestones of St. Gerand-le-Puy, with rich fauna of mammals, present only in the northern part of the Limagne. Basal Miocene in age
4. Lacustrian limestones including *Phryganea* limestones, some *Limnaea* and *Helix ramondi*, that is, of Chattian, upper Néonummulitique (Upper Oligocene) age
3. Alternating marls and marly limestones with *Cypris* (therefore of lacustrian formation), overlain by marls of lagoonal facies with *Potamides lamarcki*, and with gypsum intercalations. These formations, especially the *Cypris* marls, fill the major part of the Limagne syncline. They belong to the Stampian (Rupelien), middle Néonummulitique (Middle Oligocene) age
2. Marls, with some alternating sandstones, including, at the base and on the borders, some arkoses, formed from the crystalline rocks. The lagoonal fauna of these deposits is clearly Sannoisian (Lattorfian), of the lower Néonummulitique (Lower Oligocene) age.
1. Crystalline basement

Some Oligocene deposits are also found on the crystalline tablelands bordering the Limagne on the east and west, but only in the form of thin remnants, nearly all of which date from the early Oligocene.

[1]Manuscript translated by Winthrop P. Haynes; received, March 1, 1932.

[2]Chief of the department of applied geology, Faculté des Sciences, Paris.

FIG. 1.—Outline map of France showing location of Limagne area.

The Limagne structure is simple; the synclinal disposition of the Oligocene series is accentuated by north-south faults, particularly important on the two borders of the plain where they bring into direct contact the crystalline rocks and the *Cypris* marls. The best known of these faults goes through Royat, in the vicinity of Clermont-Ferrand, on the western border. In this region the crystalline plateau terminates abruptly, dominating the plain by about 1,650 feet. The age of these faults can not be defined precisely; we know only that they affect the diverse stages of the Oligocene sedimentary series already described, and even some eruptive Miocene lava flows. Therefore, it has been thought that the principal sinking of the Limagne syncline occurred near the end of the Miocene. Up to that time, since the beginning of the Oligocene,

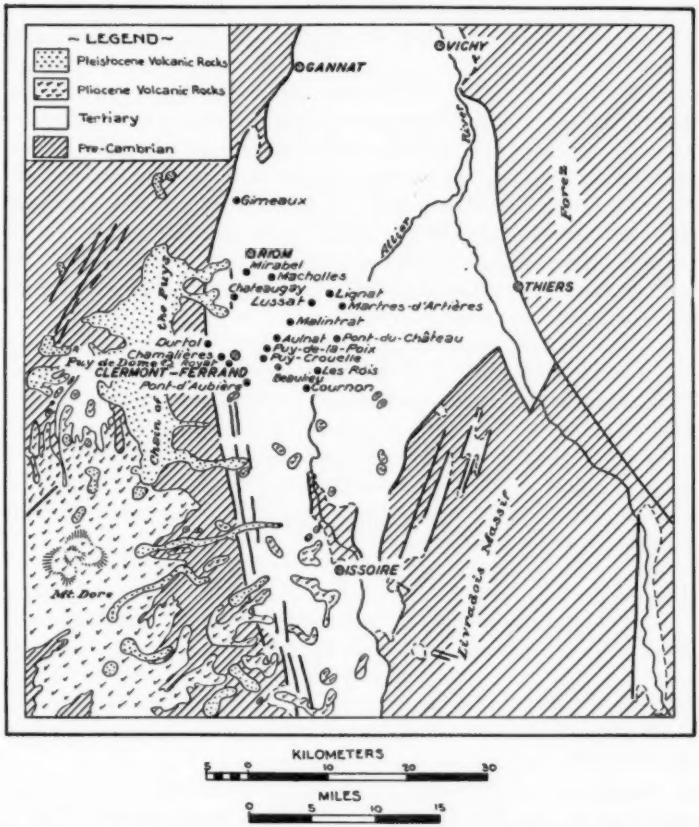

FIG. 2.—Limagne graben of Oligocene sedimentary rock bounded on west by Volcanic Chain of the Puys, and of Mount Doré, and on east by crystalline rocks of Livradois Hills massif and of the Forez. (Redrawn from Glangeaud.)

the synclinal was sinking progressively, and at the same time, filling. In reality, it is more likely that the faults commenced much earlier (Sannoisian age), bringing a rapid sinking of the old syncline. By judging from the present height of the Oligocene remains lying on the plateaus, it is possible to estimate the sinking of the bottom of the syncline, along the axis, as at least 5,900 feet. Only faulting has disturbed these deposits, and till now no folding of importance has been detected.

VOLCANISM

At the end of the Tertiary and at the beginning of the Quaternary periods there were several important volcanic eruptions in the Limagne as well as on the crystalline plateaus surrounding it. The oldest basaltic occurrences of the Limagne are usually thought to be of Lower Miocene age (Burdigalian). They exist now only as lava caps, topping some hillocks of Oligocene marls. New volcanic activity occurred between the close of the Miocene and the glacial period, but the most recent eruptions were localized in the Puys Chain, and only the lava flows caused by them spread over the Limagne plain. At present, the volcanic activity manifests itself only through cold carbon-dioxide fumaroles and some hydrothermal springs.

There are in Limagne many basaltic or hyperitic necks and dikes which, crossing the marly limestone formations of the Oligocene, produce laccoliths of a very special kind of rock, due to the partial digestion of these sedimentary formations by the eruptive magma; these are called "pépérites," and correspond with agglomerates. The age of the pépérites is certainly variable; some of them are of Pliocene age and it is probable that others are of Quaternary age. Their outcrops are especially numerous southwest of Clermont-Ferrand.

INDICATIONS OF HYDROCARBONS

Traces of hydrocarbons are numerous in Limagne, more especially in the central region. The only known surface traces are seepages of heavy asphaltic bitumen, and some asphalts. They are found in the different beds of the Oligocene series, but they are equally numerous in the pépérites. The most important hydrocarbon occurrences are as follows.

1. In some arkoses at the base of the Oligocene series or in arkoses equivalent to the *Cypris* marls: asphaltic impregnations at L'Escorchade, near Chamalières (west of Clermont-Ferrand), and at Lussat (7½ miles northeast of Clermont).

2. In the *Phryganea* and *Helix ramondi* limestones: important deposits of asphaltic limestones at Pont-du-Château (on Allier River), small similar deposits at Lempdes and at les Rois (southeast of Pont-du-Château).

3. In the pépérites: impregnations at Puy de la Poix (2½ miles east of Clermont), with sulphur spring with asphalt traces; similar impregnations at Aulnat, Malintrat, and Lignat (northeast of Clermont), and Cournon (southeast of Clermont).

4. Near Châteaugay bitumen seeps out along a volcanic neck.

5. Between Durtol and Royat traces of bitumen have been found in the granite crushed by faulting.

HISTORY OF DRILLING

Numerous borings have been made in Limagne during the last 50 years. They may be grouped in the following way.

1. Excavations for petroleum by small shallow test holes at Puy de la Poix, Pont-du-Château, Lussat, Malintrat, and Macholles.

2. A deep well was drilled at Macholles in 1896; it reached a depth of 3,818 feet without reaching the crystalline basement beneath the Oligocene. Slight traces of oil and gas were observed at 1,968 feet and at 3,610 feet. The oil at 3,610 feet was a very fluid yellow-brown oil, with 6-7 per cent of sulphur and a density of about 16° Bé. gravity.

3. Five shallow wells were drilled: two at Puy de la Poix (295 and 350 feet), one at Gandaillat (338 feet), one at Pont d'Aubière (226 feet), one at Grand-Beaulieu (148 feet). These were drilled in 1921 and 1922, giving negative results or only traces of bitumen.

4. A well drilled at Gimeaux (northwest of Riom) in 1921, reached a depth of about 1,310 feet, without any important showings; warm water was encountered at 495 feet.

5. A well at the Martres d'Artières, commenced in 1919, reached a depth of 1,361 feet. Only seepages of heavy bitumen associated with thermal spring waters, and carbon dioxide, were encountered, between 1,046 and 1,050 feet, and at 1,361 feet. The bitumen contained about 10 per cent of sulphur.

6. The drilling at Puy Crouelle (1920-1922) reached a depth of 2,808 feet through the Stampian, *Cypris* marls. Many of these gave out a strong odor of oil, but the only traces of bitumen observed were as follows: between 1,952 and 1,959 feet salt water with about 8 gallons of oil daily (15° Bé. gravity, sulphur content 9.3 per cent); at 2,790 feet a sandy horizon impregnated with yellowish brown oil, containing little sulphur; lastly, at 2,808 feet, the end of the drilling test, the casing collapsed. About 4½ barrels of oil was recovered from the well after the lapse of a few days.

7. The drilling at Beaulieu, commenced in 1923, penetrated the *Cypris* marls to a depth of 3,450 feet, then arkoses to 3,467 feet, at which depth the crystalline schists of the basement were entered. Several small bituminous impregnations were encountered, yielding heavy asphaltic bitumen.

8. The drilling at Mirabel (1925-1928), south of Riom and west of Macholles, was stopped in arkose at the base of the *Cypris* marls at a depth of 4,333 feet. Traces of bitumen were encountered at the following depths: 2,230 feet (20 barrels of oil in 5 days, 21° Bé. gravity); 2,970 feet (slight showings); 3,333 feet (80 barrels of dark brown bitumen, 9° Bé. gravity); 3,966 feet and 4,133 feet (slight traces of bitumen similar to those previously mentioned). Serious technical difficulties were encountered in drilling throughout this region. They may be due to the faulted nature of the rocks.

In all the drilling tests made in the Limagne, a low geothermal gradient is observed (about 1° C. to 50 feet).

ANALYSIS OF BITUMEN GATHERED IN DRILLINGS AT MIRABEL
(After reports in Service des Mines, Paris)

	Density	*Degrees*	*Per Cent*
1. *Bitumen from 2,230 feet*			
Color, brownish black			
Consistency, semi-solid			
Water content			18.40
Density at 150°	0.9993		
Flash point		195	
Combustion point		248	
Viscosity at 50°		329	
Fluidity, Barbey at 50°		22	
Soluble bitumen content			99.04
Ash			1.09
Sulphur			1.13
Insoluble asphalt content in benzine			11.10
Pyrogenic distillation, crude oil content			84.
Coke			10.
Water, gas, and loss			6.
Density at 15°	0.927		
Distillation of crude oil, at atmospheric pressure			
82°-180°			6.25
180°-225°			7.50
225°-300°			17.50
Above 300°			68.75
2. *Bitumen from 3,333 feet* (*Analysis by l'Ecole Superieure du Petrole de Strasbourg*)			
Water content			28.20
Bitumen content			63.25
Non-bituminous content			8.55
			100.00
Results of treating water-free bitumen			
Density at 15°	1.0054		
Hard asphalt content			9.40
Soft asphalt content			24.30
Paraffine content			3.54
Sulphur content			10.75
Ash content			8.22
Sulphur in ash			0.080
Sulphur in decantation water, 2.15 grams per liter			

Constitution of bitumen

Asphaltogenic acids	4.15
Anhydrides of asphaltogenic acids	0.62
Asphaltenes	21.42
Petroleum resins	7.70
Oily constituents	66.11
	100.00

Distillation of bitumen after Engler

50°-250°	1.5
250°-300°	17.5
300°-315°	33.0
315°-320°	2.5
Residue	41.25
Loss	2.5
Water	1.75
	100.00

CONCLUSIONS

From a general point of view, and in spite of the discovery of fluid bitumen of average density in several drilling wells, it is apparent from what has been mentioned already that the majority of the hydrocarbon occurrences in Limagne have been heavy bitumens, or possibly real asphalts, whether encountered at great depths or near the surface.

Although it has sometimes been thought that the Limagne bitumens are the result of polymerizations of gaseous hydrocarbons of volcanic origin under the action of sedimentary clays acting as catalyzers,[1] no serious evidence really exists in favor of this hypothesis. The indisputable analogies between the grabens of the Limagne and the Alsace plains, and between the Oligocene deposits that occupy these two grabens, are strong evidence of the similarity between the Pechelbronn oil fields and the bitumen of Limagne. The absence of volcanic manifestations in the region of Pechelbronn and their slight importance north of the Alsatian plain, are sufficient to suggest the existence of commercial oil deposits in this region.

It is very probable that in the two sunken grabens the hydrocarbons originated from animal or vegetable matter and accumulated in marine or lagoonal deposits and perhaps also partly in fresh-water deposits which helped to fill these grabens during Oligocene time. The rôle of the volcanic phenomena seems to have been destructive rather than constructive, and the numerous pépérite occurrences found in Limagne are very likely the cause of the absence of oils of average density comparable with those of Pechelbronn. The degradation of the ancient oil

[1] A. Guiselin, "The Petroleums of Auvergne, Their Volcanic and Chemical Origin" (in French), *Le Petrole*, New Ser., No. 37 (1925), p. 488.

beds may have been achieved in many different ways under the action of the lava flows, the thermal waters, perhaps the rapid rise of temperature observed at depth, and other factors such as heat, fumaroles, and catalyzers. It is probable that, besides simple distillation, some phenomena of cracking occurred which led to unstable hydrocarbons which were polymerized more easily than the original hydrocarbons.

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TARANAKI OIL FIELD, NEW ZEALAND[1]

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ABSTRACT

The Taranaki oil field, located on North Island, New Zealand, is an example of a small accumulation of oil in sedimentary rocks near an andesite intrusion. The oil has probably been trapped by the intrusive rock.

In the semi-commercial Taranaki field, at New Plymouth, Taranaki Provincial District, in the western part of North Island, New Zealand,[3] more than 70,000 barrels of oil have been produced to date from a zone surrounding, and within a mile of, an andesite intrusion which rises 500 feet above the Tertiary land surface. The sedimentary area is largely coincident with broad rolling plains that form the greater part of the peninsula which culminates in Mount Egmont, an extinct volcano 8,260 feet in altitude and 12 miles in diameter. The sedimentary rocks, thousands of feet in thickness, lie nearly flat, are soft and unconsolidated, form an excellent cover, have had insufficient metamorphism to distil away the oil, and are not sufficiently broken to allow it to escape.

Taranaki contains only two known types of abnormal structure: (1) intrusive plugs of post-Miocene andesite-porphyry and (2) arrested or locally reversed dips. The most prominent intrusive masses are Moturoa and the Sugar Loaf Islands at New Plymouth, but others are conspicuous in the Taranaki landscape as "conical hills." The most productive wells were drilled a few hundred feet east of the Moturoa intrusion at New Plymouth.

Because the field is situated on only slightly abnormal dip within a few hundred feet of a large intrusion, some geologists are inclined to consider the oil a product of volcanic distillation. It is probable, however, that stresses sufficient to produce slight folding were also competent to form oil without the aid of heat, and the association of oil with the andesite is probably a matter of "trapping" rather than of genetics.

[1]Manuscript received, January, 1932.

[2]Consulting geologist, 50 Church Street.

[3]F. G. Clapp, "Oil and Gas Prospects of New Zealand," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 12 (December, 1926), pp. 1227-60.

The presence of seepages in the sea near the Sugar Loaf Islands was known to natives before the advent of Europeans. The most complete account of early drilling activity is given by Clarke,[1] but later reports of the Geological Survey supply the history of operations from 1912 to a recent date. A popular journalistic account, containing noteworthy facts from the time of oil discovery until 1911, is that by Henry.[2]

Drilling commenced in 1865 and several rather distinct periods of activity ensued. From that date until 1868 a number of shallow wells were sunk near the seepages and some oil was found. In the second period, from 1889 to 1900, wells were drilled nearly 2,000 feet deep at points less than ½ mile directly east of the original shallow holes. From 1906 to 1912 several wells were deepened, finding semi-commercial oil at 2,100 to 2,300 feet, several of which still flowed at approximately weekly intervals at the time of the writer's last visit, in 1925. More recently a number of wells were deepened to more than 3,000 feet, having their best yields at about 3,100 feet, although one well reached 5,680 feet. In 1924, Taranaki Oil Fields, Ltd., commenced a test near the old shallow wells and had good showings of both gas and oil with high rock pressures, but the well was abandoned at 4,360 feet. More recent tests made by Charles N. Taylor (Moturoa Oil Fields, Ltd.) and others have continued to report production of 10-20 barrels per day from depths ranging from 2,100 to 3,300 feet.[3]

Much of the gas associated with oil produced near igneous intrusions has an unusual composition, and analyses of the product of New Plymouth wells (Table I) showed amounts from 5 to 70 per cent of carbon dioxide. Table II is an analysis of oil collected by the writer from well No. 3, of the Taranaki Petroleum Company.

Professor James Park,[4] in 1921, examined occurrences of petroleum on the east bank and in the bed of Waiotapu Stream, in Sec. 4, Block III, Paeroa Survey District and vicinity, Auckland Provincial District, in the central plateau of New Zealand, previously considered unfavorable

[1]Edward de Courcy Clarke, "The Geology of the New Plymouth Subdivision, Taranaki Division," *New Zealand Mines Dept., Geol. Survey Branch Bull. 14*, New Ser. (1912), 58 pp.

[2]J. D. Henry, *Oil Fields of New Zealand* (London, 1911), 337 pp.

[3]Personal letter received by F. G. Clapp prior to March, 1932.

[4]James Park, "Petroleum at Waiotapu, King Country," *New Zealand Jour. Sci. and Tech.*, Vol. 6, No. 3 (October, 1923), pp. 135-36.

TABLE I

ANALYSES OF GAS FROM MOTUROA, NEW PLYMOUTH,* NEW ZEALAND

Kind of Gas	*No. 1*	*No. 2*	*No. 3*	*No. 4*	*No. 5*
Methane (CH_4)	24.4	22.7	20.6	62.0	60.1
Ethane (C_2H_6)	16.3	25.8	4.7	1.6	4.7
Olefines (C_nH_m)	....	....	....	0.9	0.8
Carbon dioxide (CO_2)	49.2	43.7	72.0	30.1	31.6
Oxygen	1.3	1.3	nil	0.8	0.2
Nitrogen and other inert gases	8.8	6.5	2.7	4.6	2.6
Totals	100.0	100.0	100.0	100.0	100.0

*Dominion Laboratory, Wellington, N. 2, analyst. No. 1, Well No. 2 of Taranaki Petroleum Co.; No. 2, Well No. 3, Taranaki Petroleum Co.; No. 3, Moturoa Well No. 1, Taranaki Oil Fields, Ltd., depth, 1,555 ft.; No. 4, Well No. 1 of Moturoa Oil Fields, Ltd., at depth of 1,730 ft.; No. 5, same at depth of 2,330 ft.

TABLE II

ANALYSIS OF OIL FROM NEW PLYMOUTH

Distillate	*Distillation Temperatures (Degrees C.)*	*Per Cent*
Gasoline	80-150	20.2
Kerosene	150-300	42.0
Gas Oil	300-350	12.8
Paraffine and lubricating oil	350 upward	15.1
Coke	....	9.9
Total		100.0

for oil occurrence. The best occurrences are on a flat sinter-encrusted platform on the east bank of the stream, where many holes were seen, filled with hot water, through which rises an intermittent stream of bubbles of non-inflammable gas accompanied by "blebs of oil," Around the rim is an incrustation of dark brown or chocolate-colored ozokerite, ranging from a mere film to 2 inches thick. In the stream bed are many emanations of gas and oil; the oil breaks at the surface of the water into amber rings and floats down stream as iridescent films.

This area lies in the Roturoa-Taupo volcanic zone; and, as the surface rock is volcanic tuff, the origin of the gas and oil presents a problem of exceptional importance. In the Waikato-Waipa country on the west, the Middle Tertiary coal-bearing rocks, consisting of conglomerates, sandstones, limestones, and clays, can (according to Park) be seen to disappear below the rhyolite tuff. On the other side, east of Galatea,

the Tertiary rocks rise from below the same tuffs and he thinks the evidence points to their presence beneath the entire central volcanic region of the North Island. He considers that the brown coals of the Tertiary sediments constitute the probable source of the oil.

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NOTES ON MINOR OCCURRENCES OF OIL, GAS, AND BITUMEN WITH IGNEOUS AND METAMORPHIC ROCKS[1]

Compiled from various authors by

SIDNEY POWERS[2]
Tulsa, Oklahoma

UNITED STATES AND ALASKA

ALASKA.—Anthraxolite is found in a quartz vein cutting highly crystalline schists on Chicago Creek, about 30 miles south of Rampart (Frank L. Hess).

West of Katalla oil reaches the surface either through the joints and bedding or cleavage planes of the slate and graywacke. It is possible that the metamorphic rocks, which are known to be separated from the Tertiary shales by a fault, are overthrust upon them along a fault plane of low hade and that the oil comes from the underlying shales.[3]

ARKANSAS.—Drops of oil are reported in freshly-fractured surfaces of unweathered peridotite at Murfreesboro, Arkansas[4] (Fred P. Shayes).

CALIFORNIA. *Colusa County.*—At Wilbur Springs, Colusa County, there is a live oil seepage in serpentine (E. L. Ickes).

Los Angeles County.—Asphaltic oil seeps out of schist on the southern edge of the Santa Monica Mountains in the area now a part of West Hollywood (E. L. Ickes).

Placerita Canyon oil field, in which oil was produced from schist, is described in the accompanying paper by Arthur B. Brown and W. S. W. Kew on the San Gabriel Mountains.

In the Playa del Rey, or Venice oil field, oil has been produced in wells from schist and the overlying conglomerate of Miocene age. In both wells, casing is set above the unconformity and oil can come from both conglomerate and schist. One of these wells, Sovereign Oil Company's Sovereign No. 11, was drilled in schist from 5,953 to 6,152 feet and the cores showed oil saturation in all the cracks. The well had an initial production of only 200 barrels a day, which is probably from sand at the unconformity. The other well had an initial production of 1,558 barrels a day, but the core above the unconformity was lost and the conglomerate may or may not be present. The principal production in the field comes from the conglomerate.

[1]Manuscript received, May 1, 1932.

[2]Consulting geologist, Amerada Petroleum Corporation.

[3]G. C. Martin, "Geology and Mineral Resources of the Controller Bay Region, Alaska," *U. S. Geol. Survey Bull. 335* (1908), p. 114.

[4]No mention of such occurrences is made in *U. S. Geol. Survey Bull. 808* (1929); *Prof. Paper 154* (1929).

The structure of the field is an anticline in the Miocene and Pliocene beds above schist which may represent a buried hill. The structure was uplifted during Pliocene time because Pliocene beds thicken as much as 1,800 feet within 3 miles of the anticline (William S. W. Kew, Roy Rhoades, Clarence B. Osborne, G. Clark Gester).

Monterey County.—Seepages of heavy oil occur in a fault block of crushed granite along the San Andreas rift zone 5 miles northwest of Parkfield, in Sec. 31, T. 22 S., R. 14 E., Monterey County. The oil seeped into the crushed, and therefore porous, granite from the adjacent petroliferous Miocene shales.[1]

Another occurrence of oil is in cavities associated with cinnabar ore in the Patriquin mine, 4 miles north of Parkfield, in the Franciscan formation, ½ mile northwest of an outcrop of intrusive peridotite. The oil probably seeped in from subsequently eroded overlying diatomaceous shales (F. O. Martin).

Mono County.—A seepage of petroleum has been reported on Paoha Island, in the Mono Lake, where there are steam vents and solfataras in Recent volcanic rocks. A well was drilled for oil. There are ancient sedimentary rocks in the Inyo Range east of Mono Basin (Harry R. Johnson).

Santa Barbara County.—Oil is found in fracture cavities in serpentine in the old cinnabar mine in Santa Inez River Canyon. The oil rose with the ore along a fault zone (Clarence B. Osborne).

San Benito County.—In the New Idria cinnabar mine natural gas was encountered in rocks of the Franciscan series.[2]

Santa Clara County.—At New Almaden heavy asphaltic oil occurs in geodes and fractures in the metamorphosed rocks and serpentines of the Franciscan series (Jurassic ?) associated with cinnabar deposits. Gas was found in the mine. A rhyolite dike parallel with the ore body has brecciated the serpentine.[3]

San Mateo County.—Petroleum fills vesicles in diabase dikes on Bogess and Harrington creeks, near La Honda, San Mateo County. The oil is found inside of the calcite or chalcedony linings of the cavities.[4]

Sonoma County.—Petroleum occurs in the vesicular cavities of a basalt (?) at a locality about 7 miles east of Petaluma.[5]

Sutter County.—A gas seepage is known at the south side of the Marysville Buttes, Sutter County, at the contact of Cretaceous sedimentary rocks with the andesite core of the laccolith.[6]

[1]W. A. English, "Geology and Oil Prospects of the Salinas Valley-Parkfield Area, California," *U. S. Geol. Survey Bull. 691* (1919), p. 248.

[2]H. Ries, *Economic Geology*, 2nd ed. (New York, 1910), p. 603.

[3]*Idem.*

[4]H. L. Haehl and Ralph Arnold, "The Miocene Diabase of the Santa Cruz Mountains in San Mateo County, California," *Amer. Phil. Soc. Proc.*, Vol. 43 (1904), No. 175, p. 39; J. C. Branner, J. F. Newsom, and Ralph Arnold, "Santa Cruz Folio," *U. S. Geol. Survey Folio 163* (1909); personal communications from Frank L. Hess, Ralph Arnold, and Ralph D. Reed.

[5]R. E. Dickerson, "Tertiary and Quaternary History of the Petaluma, Point Reyes, and Santa Rosa Quadrangles," *California Acad. Sci. Proc.*, 4th Ser., Vol. 11 (1922), pp. 527-601.

[6]Walter Stalder, "Structural and Commercial Oil and Gas Possibilities of Central Valley Region, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 (1932), p. 362.

Tulare County.—In the Terra Bella oil field, wells beginning in the Kern River formation of Pliocene age have found oil in the basal arkose and in the underlying basement complex rocks of the Sierra Nevada (G. Clark Gester).

Ventura County.—The Conejo Pass oil field, Ventura County, produces from basalt agglomerate. The following description is reprinted from Taliaferro, Hudson, and Craddock.[1]

> The Conejo field, at the foot of the Conejo grade, is one of the most unusual in California as the oil is obtained from basalt agglomerate. The only rocks exposed in the vicinity of the field belong to the upper part of the Conejo volcanics, which here consist of flows of basalt and andesite, and coarse volcanic agglomerate. The latter, which is the most abundant type, is made up of large angular blocks and small fragments of basalt inclosed in a matrix of basalt or basaltic tuff. These volcanic rocks form the steep hills southeast of the town of Camarillo and also underlie the small alluvium-filled valleys within and along the front of the hills. The structure is simple, the dip being uniformly to the north at angles of 20°-28°; the strike is N. 60°-70° E.
>
> The occurrence of oil in this region is unusual for three reasons: one is the fact that the reservoir rock is sheared basalt, basalt agglomerate, or alluvium overlying these rocks; another is the very shallow depth at which the oil is encountered, 60-250 feet; and the third is that structure apparently plays little part in the accumulation.
>
> Not far north of the field the Conejo volcanics are in faulted contact with the Tertiary sediments, and it is probably along this fault that the oil rises into the volcanic rocks. There are three possible sources for the oil: (1) it may have originated in the Eocene shales below the volcanics; (2) it may have migrated into a fault, and thus into the volcanics, from the sands in the Sespe; (3) or it may have come from organic shales interdigitated with the flows and agglomerates. There is no direct evidence as to which of these hypotheses is correct. Small amounts of oil have evidently moved upward along the somewhat porous agglomerates and accumulated in the alluvium which overlies them in the shallow valleys at the edge of the hills. There is no gasoline in the oil, which has a gravity of 16° Baumé. The average production is about one-fourth of a barrel per well per day.

Six miles west of the Conejo field two wells drilled by the Western Gulf Oil Company on the Springville anticline, found heavy oil in fractures in the lower 2,000 feet of the hole which was in basaltic breccia, agglomerate, and flow material (E. L. Ickes).

COLORADO.—See the accompanying paper by F. M. Van Tuyl and R. L. McLaren.

CONNECTICUT.—Solid and semi-fluid bitumens are found in several places in amygdules in the diabase intrusives in the Triassic Newark series of the Connecticut Valley and in the bituminous shale in detached Southbury Triassic area. The localities reported are: Farmington, Hartford (Rocky Hill), Berlin, Middletown, and New Britain. The bitumen was at first mistaken for coal. It has been derived from the adjacent sedimentary rocks.[2]

[1] N. L. Taliaferro, F. S. Hudson, and W. N. Craddock, "Oil Fields of Ventura County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 808-09. See also W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753*, pp. 192-93.

[2] C. U. Shepard, *Report on the Geological Survey of Connecticut* (New Haven, 1837), pp. 62 (footnote), 152; J. G. Percival, *Report on the Geology of the State of Connecticut* (New Haven, 1842), pp. 315, 376, 384, 388; J. D. Dana "On 'Indurated Bitumen' in Cavities in the Trap of the Connecticut Valley," from the *Report on the Geology of Connecticut*, by J. G. Percival, *Amer. Jour. Sci.* (3), 16 (1878), p. 130; G. W. Hawes, *ibid.*, Vol. 9 (1875), p. 456.

ILLINOIS.—The igneous rock of a dike exposed in a coal mine between Eldorado and Harrisburg in Saline County is stained with oil (F. W. DeWolf, G. H. Cady, and R. S. Blatchley).

MICHIGAN.—See the accompanying paper by C. G. Carlson.

NEW JERSEY.—The amygdaloidal upper surface of the diabase sill of First Newark Mountain which cuts the central part of the Triassic rocks of the state contains near Plainfield vesicles of solid bitumen resembling albertite. Many of the amygdules are tubular in shape, 3 or 4 inches long and ¼ inch in diameter. Some of them are lined with quartz or calcite deposited before the bitumen was introduced. The bitumen has been derived from the overlying metamorphosed shales which contain fossil fish and obscure vegetable remains.[1]

Traces of bitumen are found in the diabase sills of the Palisades (J. Volney Lewis).

NEW MEXICO.—A basaltic dike in which oil has been found in the vesicles is located one mile from Raton. The oil is very light yellow, is extremely fluid, has a kerosene odor, and evaporates quickly (K. C. Heald).

Oil is reported in vugs and veins in a dike which extends north and south near the west boundary of T. 30 N., R. 9 W., 10 miles east of Aztec (John A. Frost).

A similar occurrence has been observed in a dike 2 miles east of Dulce, New Mexico (near Sec. 31, T. 32 N., R. 1 W.), and south of Pagosa Springs, Colorado (John A. Frost).

NEW YORK.—See the accompanying paper by J. S. Brown.

OREGON. *Lane County.*—Heavy oil in cavities, rarely in very narrow joints near the lower margin of a vesicular, inclined, basalt sill or dike near Florence, Lane County, has been described by Washburne[2] and by Harrison and Eaton.[3] Both solid and liquid oil are found in very small quantities.

Clatsop County.—In Clatsop County, near the Old Wagon Bridge, Washburne found a black, shining hydrocarbon in the vesicles of a basalt.[4]

Wheeler County.—In Wheeler County uintahite occurs in geodes at the base of a basalt flow. The locality is in Sec. 26, T. 7 S., R. 19 E., near Clarno.[5]

Crook County.—Similar geodes are found in a rhyolite dike and in rhyolite tuff in Crook County 10 miles east of Post. The asphaltic material has probably come from deeply buried rocks (Cretaceous marine sedimentary rocks ?) during crustal movement at the end of Eocene or the beginning of Miocene time. The transporting agent was water "not genetically associated with the

[1]I. C. Russell, "On the Occurrence of a Solid Hydrocarbon in the Eruptive Rocks of New Jersey," *Amer. Jour. Sci.* (3), 16 (1878), p. 112.

[2]C. W. Washburne, "Reconnaissance of the Geology and Oil Prospects of Northwestern Oregon," *U. S. Geol. Survey Bull. 590* (1914).

[3]T. S. Harrison and Arthur Eaton, *Min. Res. Oregon*, Vol. 3 (1920), No. 1, p. 26.

[4]E. T. Hodge, "Native Asphalts in Oregon," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 393-406.

[5]*Ibid.*

origin of the volcanic rocks...bearing in colloidal solution silica and petroleum emulsions." The geodes and veins acted merely as reservoirs.[1]

TEXAS. *Uvalde and Kinney counties.*—Asphalt occurs near Cline in Uvalde and eastern Kinney counties, in porous, coquina-like Anacacho limestone in proximity to faults and basaltic igneous intrusions and also in the intrusive rocks. The oil in the limestone is thought to have been distilled by the igneous intrusions and to have come up joints and fissures and to have been tarrified by hydrogen sulphide gas and sulphate water.[2]

Oil fields associated with serpentine rocks in the Coastal Plain are described in the accompanying paper by E. H. Sellards.

Brewster County.—Seepages of asphalt from basalt are found in the Terlingua quicksilver mines of Brewster County. The basalt cuts petroliferous limestones of Lower Cretaceous age.[3]

Amarillo Mountains.—The buried Amarillo Mountains extend from the westernmost granite knobs of the Wichita Mountains in Oklahoma through the Panhandle of Texas into New Mexico, a distance of 200 miles or more, with a buried relief locally in excess of 2,500 feet. These mountains, as known from well samples, consist of a core of pre-Cambrian igneous rocks, overlain unconformably by arkoses, dolomites, and red beds of Pennsylvanian, Permian, and Triassic ages. Somewhere down the flanks of the mountains the normal sequence of lower Paleozoic limestones and shales must rest against the granitic rocks just as they do on the north flank of the Wichita Mountains.[4]

Gas fields have been developed along the axis and oil fields along the flanks of the buried mountains at depths ranging from 1,500 to 3,500 feet. Part of the production comes from arkose, weathered granitic rocks, including residual boulders, and to a small extent from joint planes and fissures in very slightly weathered or fresh granitic rocks, such as the characteristic rock surface under a Felsenmeer. The most common types of igneous rock are granite, diorite, and gneissoid granite. The oil on the flanks of the mountains has migrated from adjacent arkosic sandstones and dolomites into the openings in the residual igneous rocks or into joint planes.

VIRGINIA.—See the accompanying paper by Justus H. Cline.

WASHINGTON.—The occurrence of methane gas in basaltic flows in the Rattlesnake Hills area, Benton County, Washington, has been known since 1913, when its existence was proved in attempts to drill for water.

The gas accumulation is found in the basaltic flows at depths of about 260, 750, and 1,260 feet, where they are sufficiently porous to act as reservoirs.

[1] *Ibid.*, p. 401.

[2] C. L. Baker, "Possible Distillation of Oil from Organic Sediments by Heat and Other Processes of Igneous Intrusion; Asphalt in the Anacacho Formation of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 995-1003; T. W. Vaughan, "Uvalde Folio," *U. S. Geol. Survey Folio 64* (1900), petrography by Whitman Cross.

[3] J. T. Lonsdale, "Analcite from Brewster County, Texas," *Amer. Min.*, Vol. 13 (1928), p. 449.

[4] C. Max Bauer, "Oil and Gas Fields of the Texas Panhandle," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 733-46 (with references).

In each case immediately above them in the porous phase there is dense plastic clay of variable thickness composed largely of bentonitic material and green to white clay permeated with fine particles of volcanic ash.

The basaltic flows of Miocene age are folded into a large anticline which can be traced from the Rattlesnake Hills northwestward almost to the east flank of the Cascade Mountains.

Near the gas field the anticline has been faulted for several miles along the axis of the fold with the downthrow on the northeastern flank. The vertical displacement is more than 1,000 feet. The gas accumulates in a structural arch which closes against the fault zone on the downthrown side. The productive area has been definitely outlined by wells in which water was encountered in the producing horizon.

The source of the gas is questioned, but has been assigned by some to carbonaceous shales between the flows. The writer believes, however, a more probable explanation is that of a deep-seated origin, possibly from beds of Eocene age which lie beneath the basaltic flows. The gas has migrated upward along the fracture zones and has accumulated in the porous parts of the basalt.

A fact which lends substantiation to this theory is that in seasons of heavy rainfall or melting snow on the Rattlesnake Hills there is invariably an increase in gas pressure in the reservoir, due to the filling of fracture zones near the surface by water and silts, thus forming a more effective seal to prevent gas escape.

It is also thought that the extremely low reservoir pressure (16 ounces when operated and 24 when the wells are closed) simply represents the frictional resistance to the escape of gas along the fracture zones and that the gas has been escaping in small quantities through an extremely long period of time. At present there are 15 producing wells and the production is about 4,000,000 cubic feet a day, which is piped to the small cities within a radius of 25 miles.

A detailed report on the geology of this area has been prepared by Solon Shedd, but only the map and abstract have been published[1] (A. A. Hammer).

Semi-solid oil in veins which cut Eocene basalts near Ilwaco, Pacific County, has been described by Hudson.[2]

WYOMING.—Asphalt and heavy asphaltic oil from seepages were used as fuel for many years by sheep herders on Copper Mountain, T. 4 N., R. 92-93 W., northeastern Fremont County, near the geographic center of Wyoming. This oil occurs on the surface and in shafts and tunnels in granite of pre-Cambrian age high on a denuded anticline whose granite core is more than 15 miles long and 8 miles wide. The oil exudes from fault planes.

[1]Solon Shedd, "Geologic Map of Pasco and Prosser Quadrangles, Washington," *Dept. of Conservation and Development Bull. 32* (Pullman, Washington, 1925), Pl. 1; Harold E. Culver, Abstract on the Report on the Geology and Resources of the Pasco and Prosser Quadrangles (by Solon Shedd), *Dept. of Conservation and Development Rept. of Investigations 1* (Pullman, Washington, 1926), 5 pp., mimeographed.

[2]F. S. Hudson, "Occurrence of Oil in Basalt in Southwestern Washington," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 87-88.

Trumbull[1] interpreted the origin of the oil as a remnant of an oil field which accumulated on the dome in rocks of Embar (Permian) age and in the underlying granite before the sedimentary rocks were removed. Oil migrated laterally into the dome and both upward and downward in the fault planes. Outcrops of Embar limestone and Chugwater sandstone (Triassic) on the north flank of the mountain are saturated with oil, and outcrops of Tensleep sandstone (Pennsylvanian) on the east end of Copper Mountain have oil seepages.

NORTH AND CENTRAL AMERICA (EXCEPTING UNITED STATES AND ALASKA)

GREENLAND.—Traces of petroleum are reported in basalt on Disco Island.[2]

NEWFOUNDLAND.—Bituminous shales and thin limestones of the Levis formation, of Ordovician age, cropping out along the west coast of Newfoundland from Cape St. George on the southwest to the Straits of Belle Isle, are cut by diabase dikes between Port-au-Port Bay and Bonne Bay.

"The igneous and intrusive masses of trap which disrupt the strata at so many points frequently contain nests and strings of anthraxolite."[3] One locality is in Port-au-Port Bay opposite Fox Island.[4]

CANADA. *Quebec.*—Sir William Logan described a coarse-grained diabase dike at Tar Point,[5] Gaspé Bay, Gaspé Peninsula, cutting Gaspé sandstone of Lower Devonian age in which small druses and joints are filled with petroleum which, in some places, has hardened to the consistency of pitch.[6] The cavities and cracks are lined with chalcedony and the centers are filled with bitumen which seeped in after the dike cooled. The dike is parallel with, and close to, the axis of an anticline.

Seepages of oil are common in this area and many wells have produced a small quantity of oil.[7]

[1]L. W. Trumbull, "Petroleum in Granite," *Wyoming Geol. Office Bull. 1* (1916). No mention of the seepages is found in *U. S. Geol. Survey Prof. Paper 51* on the "Geology of the Big Horn Mountains," by N. H. Darton; personal communication from W. W. Boyer.

[2]A. I. Stigand, *Outlines of the Occurrence and Geology of Petroleum* (London, 1925), p. 144.

[3]James P. Howley, *Geol. Survey of Newfoundland Rept. for 1896* (St. John's H. F., 1917), p. 27.

[4]James P. Howley, "The Mineral Resources of Newfoundland," *Geol. Survey of Newfoundland Rept. for 1892* (St. John's, 1917), p. 24; *idem*, "A Report Upon the Petroliferous Region Situated on the North-West Coast of Newfoundland," *ibid., Rept. for 1909* (St. John's, 1918), p. 42.

[5]G. S. Hume, "Oil and Gas in Eastern Canada," *Geol. Survey Canada Econ. Geol. Ser. 9* (1932), p. 137.

[6]Sir William Logan, *Geol. Survey Canada Rept. for 1863*, p. 402.

[7]W. A. Parks, "Report on the Oil and Gas Resources of the Province of Quebec," *Quebec Bur. Mines Ann. Rept. for 1929*, Pt. B (1930), p. 60.

Anthraxolite occurs in nodules as large as one inch in diameter in metamorphosed pyroxenite associated with molybdenite in Thorne Township, Pontiac County.[1] Other occurrences are near Lake Petitsikapau and Lake Mistassini.

Ontario.—Thucholite (anthraxolite) and oil are found in the Parry Sound district in a pegmatite dike which is quarried for feldspar. The mineral occurs in crystals pseudomorphic after uraninite together with thin oil and small droplets of solid asphalt-like material, both the latter occurring in cavities and cracks in two distinct cross-fracture zones that cross the dike. The country rock is gneiss and there are no sedimentary rocks in the area. The oil may have come from sedimentary rocks long since removed and have descended in the fracture zones.[2]

Another locality about 50 miles southeast of the previously mentioned locality has also been described recently.[3] Anthraxolite occurs 17 miles west of Sudbury in a metamorphosed slate.[4]

Natural gas in the harbor of Port Arthur is said to have been used to light a navigation signal for a considerable period several years ago. In 1903 a boring 1,300 feet deep on the north side of Squaw Bay, near Fort William, found inflammable natural gas in the lower 200 feet of the boring. Anthraxolite occurs in narrow veins at several places in and near Port Arthur and Fort William.[5]

British Columbia.—Seepages in the Belt series are described in the accompanying paper by Theodore A. Link. Seepages on the Queen Charlotte Islands are described in the accompanying paper by Robert M. Kleinpell.

CUBA.—See the accompanying paper by J. Whitney Lewis.

MEXICO.—See the accompanying paper by E. DeGolyer.

NICARAGUA.—At Chontales, about 10 miles northeast of Santo Tomas, near the hacienda of General Luciano Astorga and northeast of the mountains, a vein of hard asphalt about one inch thick occurs in a fault plane of small displacement cutting water-laid volcanic tuffs. The effusive rocks are interbedded with volcanic sand and conglomerate in which cycads of Jurassic age were found (Carroll H. Wegemann).

SALVADOR.—At Finca "Otuscal," between the towns of San Louis de la Reina, and Carolina, in the northern part of the Department of San Miguel,

[1]M. E. Wilson (unpublished); data from W. H. Collins, director, Geological Survey of Canada (April 4, 1932).

[2]H. S. Spence, "A Remarkable Occurrence of Thucholite and Oil in a Pegmatite Dyke, Parry Sound District, Ontario," *Amer. Min.*, Vol. 15 (1930), pp. 499-520.

[3]H. V. Ellsworth, "Thucholite," *ibid.*, Vol. 13 (1928), pp. 419-41.

[4]A. P. Coleman, "Anthraxolite or Anthracitic Carbon," *Ontario Bur. Mines Repts.*, Vol. 6 (1896), pp. 159-61.

[5]T. L. Tanton, "Fort William and Port Arthur and Thunder Cape Map-Areas, Thunder Bay District, Ontario," *Geol. Survey Canada Mem. 167* (1931), p. 200. (Data kindly furnished by George S. Hume through W. H. Collins, director, Geological Survey of Canada.)

eastern Salvador, there are Pliocene-Pleistocene lava flows, tuffs, breccias, ash beds, and interstratified fresh-water lake (?) beds containing fossil leaf and fish imprints. At the waterfall in Quebrada Grande, one mile southwest of the "Otuscal" ranch house in a dike of basaltic material, asphalt is present as fracture filling associated with calcite and chalcedony. Small geodes with crusts of chalcedony and lined with crystals of quartz and calcite are partly filled with a heavy, black asphaltic oil. It is probable that the petroliferous material resulted from distillation of the lake (?) beds by volcanic intrusions (H. J. Hawley, not previously described).

SOUTH AMERICA

ARGENTINA. *Neuquen.*—The Challacó oil field, 7½ miles northeast of Plaza Huincul and 5 miles north of Challacó, Province of Neuquen, is underlain by a buried hill of granite along a southwest-northeast Patagonian line of folding. Oil occurs in rocks of Jurassic (Sequanian) age and in the underlying granite, either in joint planes or in arkose, at a depth of about 2,600 feet.[1]

Mendoza.—See the accompanying paper by F. H. Lahee.

BRAZIL. *Paraná.*—Asphalt is found in Triassic sills and dikes and in the adjacent Permian sandstone in many localities in the Sierra da Baliza, State of Paraná. The igneous rocks are typical basalts and diabases, partly amygdaloidal. Asphalt occurs in crevices and in the pores of the igneous rock. "The occurrence of petroleum is in the contact zone of both the sedimentary rocks and the eruptives where these are completely modified by endomorphism."[2]

Santa Catharina.—Oil in vesicles in basalt occurs also in the State of Santa Catharina, south Brazil. "The basalt is absolutely fresh and solid without even the slightest cracks connecting the vesicles with the outside. Hence it is probable that the oil was present in the molten magma and was not destroyed by igneous processes."[3]

São Paulo.—Occurrences in the State of São Paulo where igneous rocks of Triassic age intrude sedimentary rocks of Permian age are as follows: (1) asphalt in crevices of a dike at Fazenda Saltinho, in Rio Tiéte, 9½ miles above Porto Martins;[4] (2) oil in vesicles in one wall of a large basalt dike 1¾ miles

[1]*Memoria de la dirección general de Minas al año 1920* (Buenos Aires, 1921); A. Windhausen, "Contribución al conocimiento geológico de los territorios del Río Negro y Neuquén," *Anales del Ministerio de Agricultura*, Seccion geología, tomo 10 (Buenos Aires, 1914); J. Keidel, *Informe geológico sobre el yacimiento petrolífero de Challacó Territorio del Neuquén* (La Casa Jacobs Preuser, Buenos Aires, 1913); C. M. Hunter, "The Oilfields of Argentina," *Inst. Petrol. Tech. Jour.*, Vol. 10 (1924), pp. 829-53; A. Windhausen, "The Problem of the Cretaceous-Tertiary Boundary in South America," *Amer. Jour. Sci.* (4), Vol. 45 (1918), p. 37, footnote; A. Windhausen, "Rasgos de las historia geológica de la planicie costanera en la Patagonia septentrional," *Boletín de las Academia nacional de ciencias en Córdoba*, tomo 23 (1918), p. 331.

[2]E. P. de Oliveira, "Petroliferous Rocks in Sierra da Baliza," *Amer. Inst. Min. Eng. Trans.*, Vol. 65 (1921), pp. 241-44.

[3]C. L. Baker, "The Panuco Oil Field, Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), p. 440.

[4]C. W. Washburne, "Petroleum Geology of the State of São Paulo," *Commissão geographica e geologica do estado de São Paulo* (Brazil, 1930), p. 147.

north of Bôa Esperança, 17½ miles southwest of Araraquara;[1] (3) bitumen converted into an anthracite-like hydrocarbon in a dike near Limeira, an analysis showing 76 per cent fixed carbon, 5 per cent volatile matter, 16 per cent ash.[2]

COLOMBIA. *Magdalena Valley.*—In the Departmento Tolima, Colombia, South America, certain oil seepages have apparently come up through an igneous rock. They are in cuts along the railway at Ambalema between kilometer 96 and Hondo in the valley of Magdalena River. The locations are at some distance from the range of mountains, Cordillera Oriental, on the east side of the Magdalena Valley, but are fairly close to the igneous mountains of the Cordillera Central on the west side of the valley.

The beds in which the oil seepages occur are in the Hondo formation of volcanic ash. The age is late Tertiary or early Quaternary. It is believed that a low-angled thrust fault has brought the igneous rocks from the west over the Guaduas beds of Upper Eocene age. Uptilted oil sands of Eocene age probably allow the oil to seep up through the igneous rock into the flat Hondo beds.

An oil company drilled a hole in this area and abandoned it on penetrating igneous rock, probably granite. The explanation of the oil seepage is that the orogenic push from west to east contorted the underlying sedimentary rocks into folds from which the oil escapes through faults and fissures. Both Eocene and Cretaceous beds farther down the valley contain oil.

An article by Stützer[3] mentions some asphalt and oil occurrences in igneous rock at a point between Nare and Puerto Berrio in Departmento Antioquia. This location is approximately 100 miles slightly east of north from the seepages described in Tolima.

It is Stützer's idea that the Magdalena Valley is a graben and that oil from the Tertiary down-faulted rocks penetrates the adjoining igneous rock. He believes that the oil comes up through fissures in the igneous rock to the surface. Naturally the fault is supposed to be normal.

There are facts in the geology of the Magdalena Valley which indicate that there is no graben and that the fault on the west side of the valley is an overthrust. To understand the situation, it is probably necessary to say a word about the stratigraphy of the oil-bearing beds.

[1] *Idem*, p. 150.

[2] I. C. White, "Report on the Coal Measures and Associated Rocks of South Brazil," report made by the Coal Commission to the Brazilian Government (Rio de Janeiro, 1907).

[3] Otto Stützer, "Erdöl- und Asphaltaustritte in Eruptivgesteinen und Kristallinen Schiefern des Mittleren Magdalenentals," *Zeit. d. D. Geol. Ges.*, Bd. 75 (1923). *Monatsbericht*, Heft 11-12. See also, Fritz Weiske, "Memoria detallada de los estudios del Rio Magdalena, obras proyectadas para su arreglo, y resumen del presupuesto," *Minerva* (Bogota, 1926); J. V. Harrison, "The Magdalena Valley, Colombia, South America," *XV Int. Geol. Cong.* (South Africa, 1929), *Comptes Rendus*, Vol. 2, pp. 399-410; H. deBöckh, G. M. Lees, and F. D. S. Richardson, "Contribution to the Stratigraphy and Tectonics of the Iranian Ranges," in *The Structure of Asia*, J. W. Gregory (London, 1929), p. 164.

These are presumed to be Upper Eocene as determined by *Foraminifera* recently discovered. The beds are generally known as the Guaduas and lie unconformably on the older Eocene Guadalupe formation (Misoa-Trujillo beds of Venezuela). Above the Guaduas come the Barzalosa beds of Miocene age. The Hondo beds are probably Pliocene. These last beds were apparently laid down subsequent to the faulting and in many places overlie igneous rock.

There are Cretaceous beds on the east side of the valley, at least for a portion of its extent, and igneous rocks, possibly of early Tertiary age, on the west side. Evidence exists in the Eastern Cordillera of the Andes of a tremendous push from the west. In this squeeze it is quite possible that the Bogota plateau was uplifted and also slid over beds of younger age. The igneous rocks of the Cordillera Central quite possibly slid over the sedimentary rocks lying farther east and in the present Magdalena Valley. Farther south in Tolima at a place called Las Piedras opposite Guatequi, granite overlies Tertiary beds of the Barzalosa formation.

The conclusion on the matter of these seepages is that they result from oil sands underlying the igneous rock rather than from oil sands in simple juxtaposition. The appearance of seepages at the surface is due, perhaps, to their penetration of the igneous rock fissures. Where covered by the porous Hondo beds of volcanic ash, secondary oil sands result (W. J. Millard).

ECUADOR.—On the Santa Elena peninsula the seepages and hand-dug pits for oil are clustered along the principal outcrop of Tertiary chert and indurated shale near igneous dikes. The greatest saturation of oil is in sands in the excessively shattered areas, many of which are close to the dikes. At the time the shales and sandstones were folded and intruded, the oil was probably segregated primarily by the influence of the thermal agencies connected with the intrusions and accumulated in the crushed and shattered zones in the axial area of the principal structure. Subsequent erosion has dissipated much of the oil from the superficial strata, leaving inspissated residues.[1]

All of the production of Ecuador has come from the Santa Elena area. More than 2,000 pits have been dug and the oil recovered from them varies from 24° Bé. gravity to almost pure asphalt. Many wells have been drilled and some of them have yielded oil of 35°-37° Bé. gravity.[2] At the present time most of the production comes from wells.

PERU.—In several localities veins of solid asphalt, in places approximating a graphitic mixture of hydrocarbons, occur in sedimentary rocks at the contact and in the vicinity of young eruptive rocks. The asphalt has been distilled by the heat of volcanic action and trapped in the fissures caused by the igneous activity. Vanadium is associated with the asphalt. The principal

[1]Abstracted from George Sheppard, "Relation of Volcanic Dikes to Oil-Bearing Formations of Southern Ecuador, South America," *Econ. Geol.*, Vol. 21 (1926), pp. 70-80. See also E. H. Cunningham Craig, *Oil Finding* (London, 1920), p. 81; Joseph H. Sinclair and C. P. Berkey, "Cherts and Igneous Rocks of the Santa Elena Oil Field, Ecuador," *Amer. Inst. Min. Eng. Trans.*, Vol. 69 (1923), pp. 79-95; George Sheppard, "Observations on the Geology of the Santa Elena Peninsula," *Inst. Petrol. Tech. Jour.*, Vol. 13 (1927), pp. 424-61.

[2]Joseph H. Sinclair, "Oil Development in Ecuador During 1923," in "Production of Petroleum in 1923," *Amer. Inst. Min. Eng.* (1924), pp. 199-207.

occurrence is at Minasragra, near Cerro de Pasco, where beds of Neocomian age are cut by rhyolite dikes. A vanadium-bearing asphaltite vein 16 feet long occurs on both sides of a rhyolite dike. This vein yields about 80 per cent of the world's supply of vanadium. Another locality is in Lacsacocha (Yauli). Where the thin vanadium-bearing asphaltite veins are at the contact of sedimentary rocks with intrusive andesite, they resemble graphite.[1]

VENEZUELA. *Inciarte.*—Extensive seepages of heavy oil and asphalt deposits are found in the Inciarte area, 60 miles west of the city of Maracaibo in the district of Mara in sedimentary rocks of Upper Tertiary age. The asphalt deposits were worked commercially for a number of years, but operations have not been carried on here since 1905. More than 100,000 tons of asphalt were mined in the years 1901-1905.

The presence of these seepages, in conjunction with evidence of surface structure, led to the drilling of four wells in the area during the years 1916-1918. Granite was found in the wells at depths varying from 420 to 2,017 feet, and this discovery led to the suspension of drilling and the abandonment of the area.

Southwest of Inciarte, granodiorite is exposed at the surface, probably as an extension of the frontal granitic ridge of the Sierra de Perija as at Totumo, and it is considered that the igneous rock below the surface at Inciarte is an extension of this spur, probably a buried hill. The well logs give evidence of weathering.

Some of the wells made good showings of oil after penetration of the broken and probably eroded surface of the igneous rock. It is thought that the presence of oil is due to lateral (upward) migration from the east where the buried petroliferous Cretaceous is probably in contact with the granite.

The gravity of the Inciarte oil is about 10° Bé. Some of the wells made as much as 3 or 4 barrels daily. All had showings of oil (W. D. Miller and J. Edward Brantly).

Cachiri.—Cachiri is 3 miles northwest of Inciarte. An active seepage of heavy oil issues from basalt. Several shallow wells had showings of oil at the contact of the basalt and sedimentary rocks or, possibly, within the basalt (Brokaw, Dixon, Garner, and McKee).

Totumo.—The Totumo (Rio Palmar) oil field is on the mountain front of the Perija Mountains, in the district of Perija about 65 miles southwest of Maracaibo, between Rio Palmar and the base of the Perija Range. The Caribbean Petroleum Company drilled the first well in 1914 at a large seepage of black asphalt. The location was made by Ralph Arnold. Another seepage, issuing from granodiorite, is located 1½ miles northwest of the first well. The seepages occur along a major fault separating sedimentary from igneous rocks.

Eleven oil wells were reported in this field at the end of 1929. The second well drilled was reported to have an initial production of 300-500 barrels a day, the third well 2,000 barrels, and the last seven were estimated from 10 to 350 barrels each.[2] The large wells indicated possibly good production. The gravity is 20°-23.8° A. P. I. No pipe line has been built to the field.

[1]G. Steinmann, *Geologie von Perü* (Heidelberg, 1929), with references. D. F. Hewett, "Vanadium Deposits in Peru," *Amer. Inst. Min. Eng. Trans.*, Vol. 40 (1909).

[2]R. E. Leigh, *The Oil Weekly* (December 13, 1929), p. 77.

The wells begin in mottled clays of Miocene age and are located within a few hundred feet of the igneous outcrops. They drill through fractured quartzites, quartzitic conglomerates and shales, and have good showings of oil in these rocks at depths ranging from 700 to 2,500 feet. The largest of them, including the second and third drilled, penetrated trachyte or serpentinized granite porphyry. The oil from these two largest wells comes from depths ranging from 175 to 400 feet below the level at which igneous rock was first found. Small production was found in the overlying sedimentary rocks.

Accumulation of oil and gas within the igneous rocks is presumably due to fissuring in conjunction with the major fault between the sedimentary and igneous rock outcrops. Migration was probably along the unconformity at the base of the sedimentary rocks.

Torondoy.—Large seepages of oil occur 25 miles southeast of Lake Maracaibo in Estado Merida. This is a mountainous country, with elevation ranging from 5,000 to 6,000 feet, cut by deep, sharp stream valleys. Single seepages or groups of seepages occur in creeks tributary to Rio Torondoy about 10 miles south of Torondoy; on Rio Torondoy at El Tabacal, about 2 miles north of Torondoy; and at La Virtudes on Rio Chiruri, which is about 6 miles northeast of Torondoy.

At the first of these localities there are about 100 separate seepages ranging in volume from oil-soaked patches to pools flowing several barrels of oil a day. The color of the oil is different in different seepages, black, yellow, and green, depending largely on the quantity of oil oozing forth.

The surface rocks in the vicinity of these seepages are granites and metamorphic rocks which are in fault contact with Upper Tertiary sedimentary rocks (probably thrust faults). The fault line connecting the last two seepages has an east-west strike and both seepages are only about 650 feet south of the Upper Tertiary sedimentary rocks cropping out on the north side of the fault. Petroliferous Cretaceous limestones are present at a higher elevation in the mountains, but 1½ miles or more farther south. The general opinion seems to be that the oil originates in the Tertiary beds across the fault line (E. S. Bleeker, courtesy of C. W. Hamilton; also, C. R. Eckes, W. Dana Miller).

EASTERN HEMISPHERE

ANGOLA.—An asphaltite called "oil-coal," or libollite, from the district of Libollo, Province of Angola, Portuguese West Africa,[1] where it occurs, has been mined in that colony. One of the best known localities is Calucala, 14 miles north of the station of Zenza do Itombe, which is 18 miles east of Luanda on the line of the Luanda-Malange railway. The libollite occurs interbedded in sandstones and conglomerates of Cretaceous age which rest unconformably on the Basement complex. The solid and viscous bitumen is believed to have been metamorphosed from oil which had accumulated in the

[1]Glen M. Ruby, "Peculiar Phases of Oil Saturation in Certain Sandstones," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 478-80. Ruby cites personal correspondence with Harry L. Baldwin and the following publication:

José Bacellar Bebiano, "Descriptive Catalogue of a Collection of Minerals together with brief notes on the Mining Prospects of the Province of Angola," *Republica Portuguesa, Governo de Angola, Direcção de Obras Publicas, Repartição de Minas* (Loanda, Angola, 1921).

sedimentary rocks as a result of more recent igneous activity. There is definite evidence of later vulcanism in the region. At a point about 3.1 miles north of Zenza do Itombe, A. C. Veatch has mapped a volcano of Cretaceous age, marked by lava flows and volcanic necks. The ash beds, which seem to be contemporaneous with these lavas, are interbedded in deposits of Cretaceous age, but younger than those in which the libollite occurs (W. B. Heroy).

AUSTRALIA.—In the Ord River basin of Western Australia, 150 miles south of Wyndham, the upper part of the vesicular basalt beds which underlie the Cambrian limestones is locally impregnated, along Ord River, near the junction of the Ord and Negri rivers, and on Stirling River, with bitumen in fissures and vesicles.[1] It softens and runs out in the heat of the sun. The oil was probably derived from the overlying, unconformable limestone, and that which is now found may be the residue of an extinct oil field from which the rest of the oil escaped.

Another occurrence was found in the Northern Territory at the Waggon Lagoon on Roper River, 350 miles east of Port Darwin, where vesicular basalt is impregnated with bitumen at its junction with quartzites, shales, and flags.[2]

BULGARIA.—Near Rakmanlare and in several other areas bitumen exudes from the centers and edges of volcanic massifs and from metamorphic rocks. It was evidently derived from the distillation of lignitic material or coal into coke by the intrusive igneous rocks before the overlying sedimentary rocks were removed by denudation.[3]

CZECHOSLOVAKIA.—Bitumen fills vesicles in melaphyre at Rybnik and Semil and in diabase at Radotin, all in Bohemia.[4]

EAST INDIES.—In Bantam, western Java, and in Palembang, southeastern Sumatra, petroleum occurs in tuffs which act as oil reservoirs bedded in the Pliocene-Miocene shale.

In the valley of Asem River north of the volcano Tangkoebanprahoe, which is 15 miles north of Bandoeng, there is a seepage of petroleum from Miocene beds close to a tongue of Pliocene lava from the volcano. Such seepages are also found in connection with other volcanoes in Java and Sumatra and probably owe their existence to fracturing and local metamorphism in connection with the volcanic activity (T. R. H. Garrett).

[1]Arthur Wade, "The Search for Oil in Australia," *Inst. Petrol. Tech. Jour.*, Vol. 12 (1926), p. 155; "Petroleum Prospects, Kimberly District of Western Australia and Northern Territory," *Commonwealth of Australia* (1924), p. 31.

[2]*Op. cit.*, *Inst. Petrol. Tech.*, p. 156; *op cit.*, *Commonwealth of Australia*, p. 37; and personal communication.

[3]A. Beebe Thompson, "The Significance of Surface Oil Indications," *Inst. Petrol Tech. Jour.*, Vol. 12 (1926), pp. 603-34, reference on p. 613; also, personal communication, dated April 1, 1932.

[4]W. Petrascheck, "Das Vorkommen von Kohle im Diabas von Radotin"; F. Slavik, "Zur Frage der Kohle im Diabas von Radotin," *Verh. Geol. Reichsanst.* (Wien, Jahrg. 1902), pp. 55-57, 194-96.

EGYPT.—Oil seeps along the planes of contact of sedimentary rocks with dikes on the Sinai Peninsula, the probable origin of the oil being the baking of the shales[1] (J. Terry Duce).

Seepages of oil associated with granite and arkose are well known at Gebel Zeit and Gemsah, on the shore of the Gulf of Suez. Oil is produced in the Gemsah and Hurghada fields from the sedimentary rocks and residual arkoses of Cretaceous age overlying granite.[2]

FRANCE.—See the accompanying paper by L. Barrabé on the Limagne area.

Bitumen occurs at Limoges, Haute Vienne, in quartz veins traversing gneiss; and gas seeps from pre-Cambrian schist and gneiss at Pontpéan, Ille-et-Vilaine, probably derived from adjacent sedimentary rocks of Oligocene age. The metalliferous veins in gneiss near Pontgibaud west of the Chain of the Puys and the Limagne have traces of bitumen.[3]

GERMANY.—Bitumen occurs in the granite of Striegau in Silesia associated with zeolites and calcite, also in cavities in granite in the northern part of the Black Forest together with calcite and covered by hematite.[4]

Droplets of oil are found in basalt intruded into the potash salts of the Werra district in central Germany.[5]

Bitumen fills vesicles in melaphyre at Oberstein in the Palatinate and other places.[6]

Bitumen occurs in phonolite of the Kaiserstuhl (Baden).[7]

Crevices in porphyry near Dossenheim north of Heidelberg are filled with asphalt.[8] The walls are studded with quartz crystals. A vein 1½ inches wide also filled with quartz crystals and asphalt in Permian conglomerate was observed by F. Röhrer, near Ottenau, northeast of Baden-Baden. He considers

[1]Petroleum Research Bulletins published in 1920-23 by the Ministry of Finance, Cairo, as follows: No. 1, p. 10; No. 4, pp. 15-16; No. 10, pp. 134-35; No. 12, pp. 41-42.

[2]A. Beebe Thompson, *Oil Field Exploration and Development* (London, 1925), Vol. 1, pp. 202-04; W. F. Hume, "Report on the Oil-Fields Region of Egypt," *Min. of Fin. Survey Dept.* (Cairo, 1916); Sidney Powers, "Reflected Buried Hills in the Oil Fields of Persia, Egypt, and Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 433-39; T. Sutton Bowman, "Boring for Oil in Egypt; Section III: Eastern Desert and Adjoining Islands," *Mines and Quarries Dept.* (Cairo, 1932).

[3]Boverton Redwood, *A Treatise on Petroleum*, 4th ed., Vol. 1 (1922), p. 179.

[4]P. Krusch, "Die Entstehung des Erdöles, verwandter Kohlenwasserstoffe und gewisser Kohle," *XV Int. Geol. Cong.* (South Africa, 1929), *Comptes Rendus*, Vol. 2 (1930), p. 294.

[5]P. Krusch, *op. cit.*, p. 293.

[6]P. Krusch, *op. cit.*, p. 294.

[7]Hans Höfer, *Das Erdöl und seine Verwandten*, 4th ed. (1922), p. 176; *Die Geologie, Gewinnung und der Transport des Erdöl*, Vol. 2 (1909), p. 236.

[8]W. Salomon, "Asphaltgänge im Quarzporphyr von Dossenheim bei Heidelberg," *Berichte über die Versammlungen des oberrheinischen geologischen Vereines*, 42 Versammlung (Karlsruhe, 1909), pp. 116-23.

the asphalt as of inorganic origin, as it is syngenetic with the quartz and the territory shows considerable thermal activity.[1]

Some oil is found in the coal basin of Dabrilugk, about 60 miles south of Berlin. The coal is traversed by dikes of keratophyre and kersantite, which have transformed it into anthracite and locally into coke. The oil is thought to have been formed by distillation on account of the igneous activity[2] (Edward Bloesch).

Bitumen occurs in ore veins in several localities: Palatinate,[3] associated with cinnabar; Hesse,[4] in ferromagnesian igneous rocks; Altenburg (Saxony), Violenberg near Grund (Harz), Kamsdorf, and Niederhausen a. d. Nahe.[5]

GREAT BRITAIN. *England.*—At Poldice, Cornwall, a small quantity of bitumen is found in granite.[6]

Oil and bitumen are found in trap in Shropshire, in basalt in Derbyshire (E. L. Ickes).

Live black oil seeps from pre-Cambrian rocks at Pitchford, Shropshire, and both hard and soft bitumen are found in pre-Cambrian slate, shale, and hard sandstone at several localities on Haughmond Hill, Shropshire (E. L. Ickes).

Bitumen occurs in a copper-bearing vein and in the granitic country rock at Carharrak, Cornwall.[7]

Scotland.—Bitumen is found in granite in Aberdeen[8] and in fissures in gneiss at Dingwall.[9]

At Cupar, Fife, a basalt dike shows moist naphtha in freshly broken surfaces.[10] Albertite is found in fissures and vesicles of dolorite cutting Carboniferous rocks in the Forth basin at West Calder and also near Edinburgh and the Isle of Mull.[11] On the Orkney Islands of Mainland, Hoy, and Shapinsay,

[1]Engler-Höfer, *Das Erdöl*, 2nd ed., Vol. 2, Pt. 2 (1930), chapter on Germany by J. Stoller, pp. 276-77.

[2]P. Krusch, *op. cit.*, p. 294.

[3]O. M. Reis in Engler-Höfer, *Das Erdöl*, 2nd ed., Vol. 2, Pt. 2 (Leipzig, 1930) pp. 274-75.

[4]*Ibid.*

[5]H. Höfer, *Das Erdöl und seine Verwandten*, 4th ed. (Braunschweig, 1922), p. 177.

[6]*Idem*, p. 176; A. Strahan, "Special Report on the Mineral Resources of Great Britain," *Geol. Survey England Mem.*, Vol. 7, Pt. 1 (1918).

[7]Boverton Redwood, *A Treatise on Petroleum*, 4th ed., Vol. 1 (London, 1922), p. 177.

[8]I. A. Stigand, *Outline of the Occurrence and Geology of Petroleum* (London, 1925), p. 144.

[9]J. G. Goodchild, *Mineralogy of Scotland* (Edinburgh, 1901).

[10]Boverton Redwood, *op. cit.*, p. 175.

[11]August Moos, "Grossbritannien," in C. Engler and H. Höfer, *Das Erdöl*, 2nd ed., Vol. 2, Pt. 2 (Leipzig, 1930), p. 410; from, "The Geology of the Neighborhood of Edinburgh" (Sheet 32), *Geol. Survey Scotland* (1910).

on the Shetland Islands at Walls, on the Hebrides and on Skye, albertite or oil is found associated with volcanic rocks.[1] At Gallowscrook, near Binney Craig, a volcanic neck in contact with oil shale contains mineral wax or paraffine in drusy cavities.[2] In the Broxburn district of the Lothians cavities filled with mineral wax are abundant in an intrusive dolerite sill at its contact with oil shales. One pit yielded 200 barrels of crude oil distilled from the shale by the intrusion. Natural gas has also been found at the contact.[3]

Ireland.—Bitumen is found in pores in basalts which have traversed bituminous strata in the Giants Causeway, at Newry, and Carlingford.[4]

GREECE.—Seepages of oil have been noted in the Aegean Sea at the southern extremity of Hagiostrati Island which is composed of volcanic rocks.[5]

Oil is also found in andesite north of Feredjik, Thrace.[6]

HUNGARY.—Rhyolite tuff near Recsk[7] and andesite near Nagy Bátóny and near Parád[8] (Komitat Heves), 60 miles northeast of Budapest, in the Mátra Mountains, are in places permeated by bitumen. In the copper mines of Mount Labocza near Recsk, biotite-amphibole andesite is exposed which contains drops of petroleum in small cavities[9] (Marcus I. Goldman).

ITALY.—Hydrocarbons have been extracted from obsidian, lava, and ash from Mount Vesuvius and from Stromboli and observed in volcanic eruptions.[10]

Asphalt is present at the contact with the basalt and the pyroclastic deposits of the Iblei Mountains in southeastern Sicily,[11] in the vicinity of Ragusa,

[1]August Moos, *op. cit.*, p. 411.

[2]H. M. Caddell, "The Oil Shale Fields of the Lothians," *Amer. Inst. Min. Eng.*, Vol. 22 (1902), pp. 347-53.

[3]R. G. Carruthers, "The Oil Shales of the Lothians," *Geol. Survey Scotland Mem.*, 2nd ed. (Edinburgh, 1912), pp. 50, 160-70.

[4]Boverton Redwood, *op. cit.*, pp. 160, 175.

[5]G.-C. Georgelas," Les hydrocarbures naturels en Grèce," *XIII Int. Geol. Cong.* (Belgium, 1922), *Comptes Rendus*, pp. 1355-59.

[6]Arthur Wade, personal communication dated March 30, 1932.

[7]T. Posewitz, "Petroleum and Asphalt in Hungary" (in German), *Mitteilungen aus dem Jahrbuche der Königl. Ungarischen Geol. Anstalt*, Vol. 15, Pt. 4 (1907), p. 255. This is probably the Röczk locality of M. A. Rateau, where trachytic rock is impregnated with petroleum, "Note sur l'ozokérite, ses gisements, son exploitation à Borysław," *Ann. des Mines* (8), Vol. 11 (Paris, 1887), p. 152.

[8]H. Höfer, *Das Erdöl und seine Verwandten* (1922), p. 177; F. Pávai Vajna, "Ungarn," in *Das Erdöl*, C. Engler and H. Höfer, 2nd ed., Vol. 2, Pt. 2 (Leipzig, 1930), p. 147.

[9]T. Posewitz, *op. cit.*

[10]F. Sacco, "L'origine del petrolio," *XV Int. Geol. Cong.* (South Africa, 1929), *Comptes Rendus*, Vol. 2 (1930), p. 300.

[11]Ramiro Fabiani, "Idee sulla provenienza degli idrocarburi di Sicilia," *XV Int. Geol. Cong.* (South Africa, 1929), *Comptes Rendus*, Vol. 2 (1930), p. 303; "Sulla geologia degli idrocarburi della Sicilia ancha in raporto colla formazione degli zolfi," *Boll. Assoc. Min. Sic.*, No. 3 (Palermo, 1927). E. Cortesi, "Studi... in Sicilia," Carta Geologica d'Italia, Memorie, Vol. 20 (1926).

near Scicli, and at Vizzini and Licodia Eubea. In the region of Mount Etna oil occurs in doleritic lava[1] and in basalt; north of Etna between Francavilla and Mojo, southwest of Etna as drops of oil in lavas at Paterno, farther southwest in the old volcanic region of Palagonia Mines. Bitumen is abundant in basalt at Cozzo Grillo near Cape Passero, at the southeastern tip of Sicily.[2] Stützer mentions besides oil also paraffine in the basaltic lavas of Mount Etna.[3] He is of the opinion that these substances were taken up by the lava when it broke through the Tertiary beds, which are rich in hydrocarbons (Edward Bloesch).

JAPAN.—In the Akita district the extrusive and intrusive volcanic rocks in the lowest and middle divisions of the Miocene have affected oil accumulation and oil density. In the Kurokawa field oil is produced from siliceous shales including beds of volcanic tuff and ash, from underlying basal gravels derived from igneous rocks, and possibly from the upper surface of the igneous rock. In the Katsurane field the lowest of five oil-producing horizons is a tuff at a depth of about 3,000 feet, above a core of intrusive basalt.[4] The gravity of the oil ranges from 25° to 40° Bé., the lighter oils being in the deeper sands. The effect of this intrusion on the density of oil is summarized by Kobayashi as follows.

> In the oil-bearing strata where volcanic rocks have passed, the oil has deteriorated in a number of cases into a thick, heavy variety, having a gravity less than 10° Bé. On the other hand, near volcanic rock, a light-colored oil, appearing as though it had been distilled from heavy oil, can be found.[5]

In the Echigo district, 150 miles northwest of Tokyo and 125 miles south of the Akita district, the oil is found in Miocene sands interbedded with petroliferous black shale, which rest unconformably on coal-bearing formations of Eocene age or on granite. Andesitic tuffs and flows are interbedded with shale and siliceous shale in the third and lowest division of the Miocene. White, tuffaceous sandstones, ranging from 20 to 500 feet in thickness, form the principal oil reservoirs.[6]

Natural gas from the oil deposits which are in contact with the volcanic rocks are very high in methane, with only a small percentage of higher hydrocarbons, in contrast to the "wet" gas in the younger rocks. Therefore, the

[1]F. Sacco, *op. cit.*, p. 300.

[2]R. Fabiani, *op. cit.*, p. 303.

[3]O. Stützer, *Das Erdöl* (1931), p. 112.

[4]Y. Chitani, "Geology of the Akita Oil Fields," *Pan-Pacific Sci. Cong. Proc.*, Vol. 2 (Tokyo, 1926), pp. 1597-1609. See references in W. H. Emmons, *Geology of Petroleum*, 2nd ed. (New York, 1931).

[5]G. Kobayashi, "Geology of the Oil Fields in Japan," *Econ. Geol.*, Vol. 20 (1925), p. 81.

[6]T. Iki, "Some Studies of the Stratigraphy of the Tertiary Formation in the Echigo Oil Field, Japan," *Jour. Geol. and Geog.*, Vol. 1 (Tokyo, 1922), pp. 9-90. Junichi Takahashi, "Marine Kerogen Shales from the Oil Fields of Japan," *Sci. Repts., Tôhoku Imperial University*, Ser. 3, Vol. 1 (Sendai, Japan, 1922); *Ibid.*, "On the So-Called Contact Phenomena of the Tertiary Oil Measures Caused by the Rhyolite in the Kugami-Sarugababa Region, Province of Echigo, Japan," Vol. 2 (1924). Also see references in W. H. Emmons, *op. cit.*

intrusions may have caused changes in chemical composition of both oil and gas as a result of thermal decomposition.[1] Gas of volcanic origin issues from andesite and from fissures in granite.[2] They are of two types, those rich in carbon dioxide and in nitrogen, respectively.

JUGOSLAVIA.—At the south end of the Moslavina Mountains, in Croatia, gneiss is faulted against Pontic (Pliocene) beds. Along the fault plane gas escapes, also asphaltic oil, which has impregnated the gneiss along crevices. Near Mikleuschka, southeast of Zagreb, this oil was exploited at one time by underground mining[3] (Edward Bloesch).

MADAGASCAR.—Volcanic dikes which criss-cross the oil-bearing area of western Madagascar have played an important part in the generation of petroleum, according to the following quotations from Wade.

> Where such dikes are absent or rare, we found no seepages, no tar sand. Such seepages and tar sands become more important and prolific directly as the dikes become more numerous, until we get the greatest concentration of petroleum at Bemolanga, region of intense volcanicity.... It certainly appears as though the petroleum in these areas had been distilled from the carbonaceous matter present in the (Tertiary) beds by the heat which emanated from the intrusives.... The uncommon factor in this case is the extent, both as regards area and the amount of petroleum produced. Possibly this mode of origin explains the peculiar fact that the oil at Bemolanga in sands forming the surface is often so light in character... these sands may have only become impregnated during a comparatively recent period.[4]

MANCHURIA.—Solid bitumens were found in the pores of basalts southwest of the railroad station Manchuria (Manchouli) on the Chinese-Eastern Railroad. They are considered to be distillation products of lignites cut by the effusive rocks (I. P. Tolmachoff).

NEW CALEDONIA.—An oil seepage occurs at the northwest end of New Caledonia, near Koumac, in folded Eocene rocks, close to the contact of an intrusive post-Eocene peridotite stock, now almost completely serpentinized (Walter L. Whitehead).

NEW ZEALAND.—See the accompanying paper by Frederick G. Clapp.

[1]K. Uwatoko, "Sedimentary Natural Gases from the Oil and Coal Fields of Japan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 192; C. Bone, *Jour. Chem. Soc.*, Vol. 98 (1908).

[2]*Idem*, "Natural Gases of Igneous Origin in Japan," *Jour. Geol.*, Vol. 35 (1927), pp. 557-69.

[3]Engler-Höfer, *Das Erdöl*, 2nd ed., Vol. 2, Pt. 2 (1930); chapter on Jugoslavia by L. Sommermeier, p. 188 and Pl. 1.

[4]Arthur Wade, "Madagascar and Its Oil Lands," *Inst. Petrol. Tech. Jour.*, Vol. 15 (1929), pp. 2-33, quotation from p. 27. See also, C. P. Nicolesco, "Petroleum Reserves of Madagascar," *La Revue Pétrolifère* (Paris, September 6, 13, and 20, 1930).

NORWAY.—Asphalt is found in pegmatite veins cutting Archean gneiss at Narestö, Arendal,[1] and in ore veins at Lillebö and Kongsberg.[2]

PERSIA.—At a point 1¼ miles south of Genasem on the Zelim Rud and 24 miles by air line southeast of Sari, in Mazandaran Province north of the Elburz Mountains, and near the Caspian Sea, efforts were made by the Russians many years ago to extract oil from an ancient seepage approximately 2,000 feet above sea-level. Half a pint of light yellow oil with sweetish taste and odor was collected there by the writer in 1927 from old pits in surface débris and apparently overlying Mesozoic limestone only a few hundred feet distant from a porphyritic dike. Fractionation of the small sample by the writer resulted in yielding 37 per cent gasoline, 43 per cent kerosene, 7 per cent lubricating oil, and 8 per cent paraffine (Frederick G. Clapp, original observation).

At the southern extremity of the lava flows from Mount Ararat large oil seepages issue from a fault less than 3,000 feet from an extinct crater. The sedimentary rocks are compact and massive shales which were evidently fractured and faulted by the igneous activity.[3]

PHILIPPINE ISLANDS.—On the Island of Leyte, oil seepages and veins of ozokerite[4] occur at the contact of an intrusive dike with shales and sandstones of the Vigo formation of Miocene age. At the contact the sedimentary rocks have brecciated concretion-like bodies cemented with bitumen and are baked and the dike rock is fine-grained. The oil has come from underlying Vigo shales (Roy E. Dickerson).

PORTUGAL.—Near Saccario, north of Cintra (northwest of Lisbon), drops of green oil were observed in cavities in basalt, which traverses Lower Cretaceous rocks[5] (Edward Bloesch).

ROUMANIA.—Twelve miles south of Baia Mare (formerly Nagy Bánya, Hungary, Lat. 47° 40′ N., Long. 23° 40′ E.), and 2 miles from the village of Mănaştur (formerly Monostor) there are inclusions of limestone containing petroleum and ozokerite in mica schist.[6] Rhyolite tuff is permeated by bitumen

[1]Boverton Redwood, *A Treatise on Petroleum*, 4th ed., Vol. 1 (1922), p. 199; H. Höfer, *Die Geologie, Gewinnung und der Transport des Erdöls*, Vol. 2 (1909), p. 261.

[2]A. B. Helland, "Anthracit og nogle andre kulholdige Mineralier fra Ertsleiesteder og Granitgange," *Geol. För. Förh.*, Vol. 2 (Stockholm, 1874-75), pp. 513-22; O. Falkenberg, "Geologische-petrographische Beschreibung einiger süd-norwegischer Schwefelkiesvorkommen mit besondere Berücksichtigung ihrer Genesis," *Zeit. f. prakt. Geol.*, Vol. 22 (1914), p. 152; J. H. L. Vogt, "Über die Kieslagerstätten von typus Röros...," *ibid.*, Vol. 12 (1894), p. 179.

[3]G. Maitland Edwards, discussion of paper by Eugene Coste, *Inst. Min. Met.*, Vol. 21 (1912), p. 161.

[4]W. E. Pratt, "Petroleum and Residual Bitumens in Leyte," *The Philippines Jour. Sci.*, Vol. 10, No. 4, Sec. A (July, 1915).

[5]Engler-Höfer, *op. cit.*, chapter on Pyreneic Penninsula by A. Moos, p. 403.

[6]J. Noth, "Petroleum Vorkommen in Ungarn," *Verhandlungen der k. k. geol. Reichsanstalt* (1885); H. Zapalowicz, "Geologische Skizze des östlichen Theiles der Pokutisch-Marmaroscher Grenzkarpathen," *Jahrbuch der k. k. geol. Reichsanstalt* (1886).

at Coas (formerly Kövás) west of Mănaştur.[1] I. P. Voitesti states (personal communication) that these localities are on the north flank of the Preluca (Prelukai) crystalline "island" and that there are seepages in the Miocene rocks (Sarmatian ?) which transgressively overlap the older rocks.

In rhyolitic quartz trachyte of Mount Kapus, near Căpuşul Mic (formerly Kis), Căpuşul Mare (formerly Kapus, 46° 48′ N., 23° 20′ E.), 16 miles west of Cluj (formerly Kolozsvár, Klausenburg), there are small quantities of asphalt in cavities and veins.[2] Most of the seepages here and at Zibau (Zsibo, 47° 15′ N., 23° 18′ E.) are in the Paleocene, Untere bunte Tonschichten of Koch, according to Voitesti (M. I. Goldman).

RUSSIA (U.S.S.R.).—In Kamchatka oil and gas seepages have been discovered in the valley of Bogachevca River, the left tributary of Cronovca River, which flows out of Cronotskoye Lake. The seepages are about 35 miles from the sea. The valley of Bogachevca, about a mile wide, is filled with morainic material and dissects a high plateau composed of basaltic and andesitic lavas and layers of volcanic tuffs. No sedimentary rocks were discovered there, but Tertiary beds were found on the sea shore overlying basalts. In the region of Bogachevca River the Tertiary sedimentary rocks are apparently covered by volcanic rocks, and the latter may represent an intrusion into Tertiary strata. There is no mention in the available literature referring to oil in lavas. Oil percolates into the river and accumulates on the banks, on the surface of the water, and beneath the pebbles on the bottom. The oil originates in the sedimentary rocks although the seepages are close to the volcanic rocks (I. P. Tolmachoff).

Anthraxolite has been found in microgranulitic keratophyre on the southern shores of the Crimea on Cape Parthenit and near the village of Lemeny and in Siberia near the river Toim (Lat. 54° 30′ N., Long. 89° 56′ E.). The mineral occurs as small nodules ½-¾ inch in diameter inside cavities lined with calcite and quartz; therefore, it represents a later vein formation of bitumen distilled from the sedimentary rocks cut by the eruptive rocks.[3]

SWEDEN.—At Nyhamn, several miles northwest of Helsingborg, the Lower Silurian slates are traversed by diabases and some of the vesicles contain petroleum. Another occurrence is at Hünneberg, near Wenersberg. In Wermland asphalt permeates mica schist in two localities and fills veins in gneiss in two other localities. The bituminous matter was derived from overlying beds since removed by erosion. Bitumen occurs associated with ore deposits at Kallmora, Falun, Dannemora, and elsewhere.[4]

[1]T. Posewitz, "Petroleum and Asphalt in Hungary" (in German), *Mitteilungen aus dem Jahrbuch der Königl. Ungarischen Geol. Anstalt*. Vol. 15, Pt. 4 (1907), p. 255.

[2]Antal Koch, "Mineralogic Contributions from Siebenbürgen" (Hungarian) *Orvos-term. értesitő*. (Kolozsvár, 1890); J. Grybowski, "Mikroskopische Studien über die grünen Conglomerate der ostgalicischen Karpathen," *Montanzeitung für Oesterreich-Ungarn* (1896), Nos. 23, 24.

[3]W. W. Arschinow, "On Inclusions of Anthraxolite (Anthracite) in Igneous Rocks of Crimea," *Lithogaea*, G. 50 (Moscow, 1914), 15 pp. (in Russian, abstract in English). Also, VII Int. Geol. Cong. (St. Petersburg, 1897), *Guide Book 33*, p. 7.

[4]Boverton Redwood, *op. cit.*, p. 199; H. Höfer, *Die Geologie, Gewinnung und der Transport des Erdöls*, Vol. 2 (1909), p. 261.

TURKEY.—Gas escapes from the vicinity of contact of serpentine masses with limestone at Chirali, giving rise to the "eternal fire." This location is on the southern shores of Asia Minor, on the Mediterranean Sea, 40 miles south of Anatalia.[1]

Near Katranly (meaning oil), 25 miles south of Erzurum, oil seeps from the contact of a basalt dike with Miocene limestone and a shallow well has produced some oil.[2]

On the south side of the Bin Gol Mountains, about 70 miles southeast of Erzurum, at Neftik (meaning pitch), in the Divani Huseyn area, there are two large lakes, one above the other, separated by a thick basaltic dike. Seepages of oil are found at contacts of serpentine with sedimentary rocks and from travertine.[3]

Another live seepage close to a ferromagnesian dike is located at Djevislik, on the east side of the Bin Gol Mountains near Hinis and about 30 miles southeast of Katranly.[4]

An oil seepage in a small stream in one locality entirely surrounded by igneous rocks is 15 miles north of the eastern end of Van Gölü (Van Lake), about 90 miles southeast of Erzurum.[5]

Oil is found in cavities in Cretaceous limestone along a fault and close to a serpentine plug at Jemagil, 22 miles south of Trabzon on the Black Sea and about 125 miles southwest of Batum, Russia.[6]

UNION OF SOUTH AFRICA.—In certain localities in Cape Colony and Orange Free State sandstone beds in contact with dolerite intrusives and vesicles in the intrusives are saturated with oil. The oil was probably distilled by heat from the intrusives out of the carbonaceous beds in the Karoo formation.[7] Gas has been encountered in several borings in the immediate vicinity of the igneous rocks.[8]

[1]Djevad Eyoub, "Petroleum Possibilities of Turkey," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), p. 664.

[2]*Ibid.*, p. 652.

[3]R. S. Blatchley, personal communication, March 16, 1932.

[4]*Idem.*

[5]Djevad Eyoub, *op. cit.*, p. 658.

[6]*Ibid.*, p. 647, and personal communication.

[7]A. W. Rogers and A. L. Du Toit, *Introduction to the Geology of Cape Colony* (London, 1909); A. W. Rogers, "Fissure Coals," *Rept. Geol. Comm.*, Vol. 15 (Cape Town, 1910).

[8]E. H. Cunningham Craig, *Oil Finding*, 2nd ed. (London, 1920), p. 4.

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